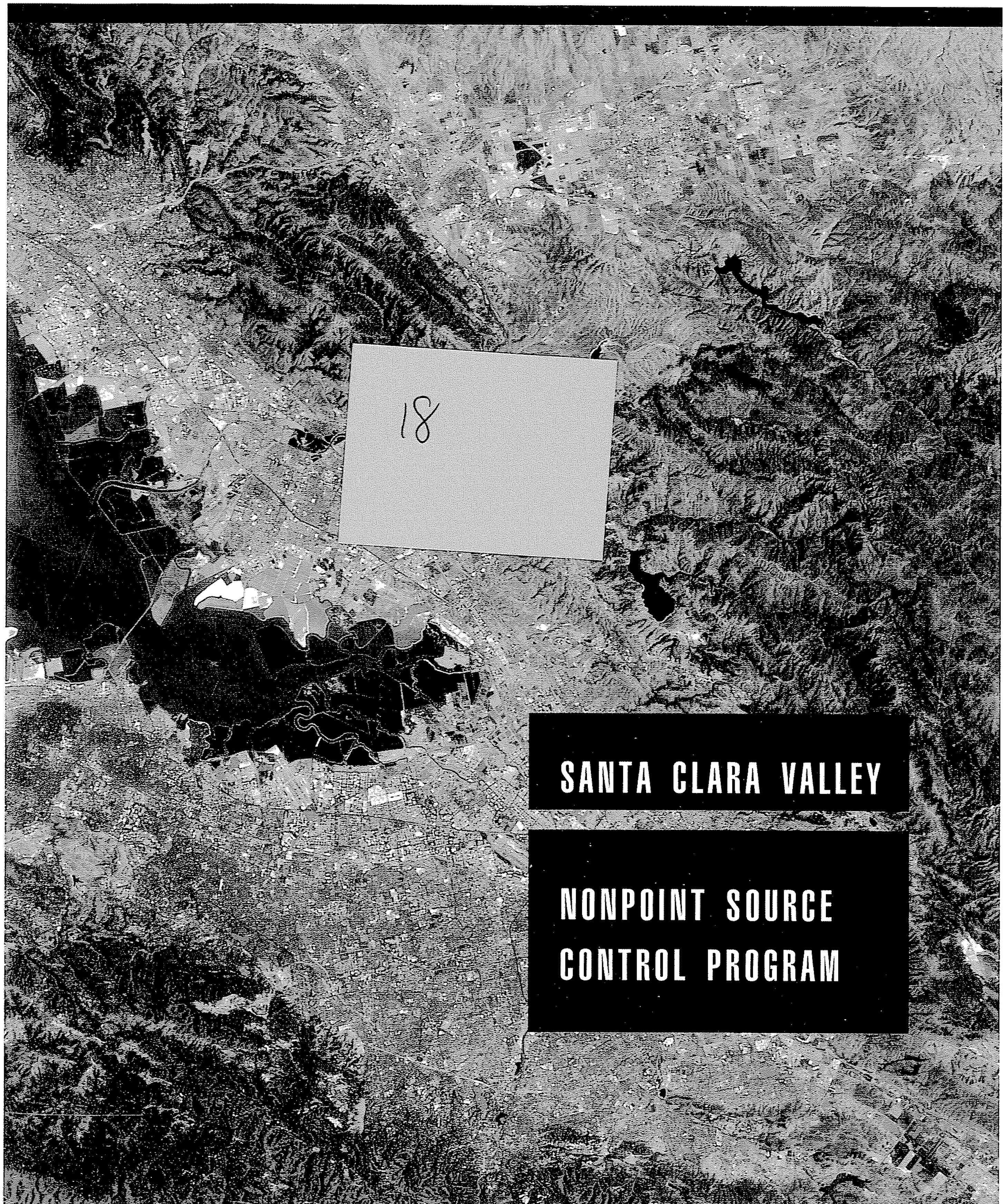
Loads Assessment Report

VOLUME I/FEBRUARY 1991



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SANTA CLARA VALLEY

NONPOINT SOURCE
CONTROL PROGRAM

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Santa Clara Valley - NPS

Loads Assessment Report
Volume I/February 1991
(Sections 1-8)

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Final Report

Santa Clara Valley
Nonpoint Source Study

Volume I: Loads Assessment Report

Submitted to

Santa Clara Valley Water District

February 22, 1991

Submitted by

Woodward-Clyde Consultants

in associated with

Kinnetic Laboratory, Inc.

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DISCLOSURE

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The program was coordinated through the South Bay NPS Task Force, which met monthly to review progress and guide the program. The chairman of the Task Force during the inception of the study was Mr. Bob Smith, followed by Mr. Roger James. Day-to-day coordination and administration of the contract was originally the responsibility of Stan Wolfe, followed by Isabel Gloege. Municipality representatives on the Task Force included Mr. Ed James (Sunnyvale), Tom Beggs and Brian Chan (San Jose), Mike Giusti (Santa Clara County), and Bruce Bane (Los Altos). Other representatives of the municipalities routinely attended Task Force meetings.

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EXECUTIVE SUMMARY

BACKGROUND

The Lower South Bay is classified by EPA and the California State Water Quality Control Board as a water quality limited segment under section 304(L) of the Clean Water Act. Because of the water quality concerns in the Lower South Bay, the San Francisco Bay Regional Water Quality Control Board (Regional Board) has pursued an active regulatory role in controlling point and nonpoint source discharges into the Lower South Bay. In their 1986 Bay Basin Plan, the Board directed Santa Clara County to develop and implement an Action Plan to (1) conduct dry and wet weather water quality monitoring "for the evaluation of both concentrations of pollutants as well as total pollutant loadings and comparison with waste loads from point source discharges," and (2) "to identify and evaluate the effectiveness of additional nonpoint source pollution control measures."

An Action Plan was developed in the summer of 1987 (CH2M-Hill and EOA, Inc., 1987), and implemented starting in the fall of 1987. The results of that implementation are documented in a three-volume series. Volume I, Loads Assessment (this report) addresses item 1 above and describes the hydrologic and water quality monitoring and modeling program and the load estimates. Volume II, Control Methods, addresses item 2 above and describes the control measure evaluation and selection process and recommends control measures to be implemented on an areawide basis in the County (WCC, 1989). Volume III, Implementation Plan summarizes the results in Volume I and II and outlines the elements and implementation schedule for the Santa Clara Valley Nonpoint Source Control Program (WCC, 1990).

PURPOSE

The primary objective of the monitoring and modeling study was to characterize the nonpoint source pollutant concentrations and annual mass loads entering the Lower South Bay from Santa Clara County. A secondary objective was to evaluate the effects of nonpoint sources on water quality and toxicity in tributary streams in Santa Clara County that enter the Lower South Bay.

STUDY AREA

The Study Area is defined as that portion of Santa Clara County that drains into the Lower South Bay (see Figure 2-3 in packet in inside of back cover). The area is approximately 690 square miles and consists of the relatively flat Santa Clara Valley bordered on the west by the Santa Cruz Mountains and on the east by the Diablo Range. The intensive development is on the Valley floor, whereas the upland areas are primarily open. Approximately 30 percent of the Study Area is residential, industry makes up about 5 percent of the Study Area and consists primarily of light industry associated with high technology manufacturing. Approximately 62 percent of the Study Area is open. The Santa Clara Valley Water District (SCVWD) operates seven reservoirs in upland areas (see Figure 2-3) as part of an extensive water supply and groundwater recharge system.

The Study Area was divided into 11 watersheds: Coyote Creek watershed (352 square miles) on the east side of the valley, the Guadalupe River watershed (170 square miles) which drains the south central portion of the valley, and a series of relatively small, more urbanized watersheds (San Tomas Aquinas Creek, Saratoga Creek, Calabazas Creek, Sunnyvale East Channel, Sunnyvale West Channel, Stevens Creek, Permanente Creek, Adobe-Matadero-Barron Creeks, and San Francisquito Creek) that drain the west side of the valley.

SCOPE OF SAMPLING PROGRAM

Sampling Stations

Given the size of the Study Area and the need to project loads from the entire area, it was not feasible to monitor the entire Study Area and thereby estimate loads based on monitoring data alone. Instead, the study was designed to develop sufficient monitoring data to calibrate and verify a watershed load prediction model, which then could be applied to estimate loads from both gaged and ungaged watersheds. For this purpose, three types of stations were utilized. "Land use stations" (of which there were eight) had small, relatively homogeneous land use catchments that in total represented major land use types found in the valley. Hydrologic and water quality data from these catchments were used as input to the loading model. "Stream stations" (four) were located in the lower portions of watersheds and had relatively large, multiple land use catchments. These stations were monitored to provide data to calibrate and verify the loading model. "Reservoir release stations" (six) were stations located just below the upland reservoirs and were used to estimate loads associated with reservoir (spillway) releases during wet years. Table ES-1 describes the various stations.

Monitoring Program Elements

The field program contained a hydrologic monitoring element, water quality monitoring element, a sediment sampling element, and a toxicity testing element.

The hydrologic monitoring element consisted of continuously monitoring water depth and flows at stream and land use stations at hourly intervals throughout the duration of the monitoring period. These data were used to help estimate the hydrologic component of the load.

Table ES-1. STATION DESCRIPTION

Designation	Type of Station	Location	Location	Jurisdiction	Principal Land Use	Drainage Area (acres)	Conveyance	Remarks
L1	Land Use	Junction Avenue, between Charcot and Dado Streets	San Jose	San Jose	industrial park	22	30" R.C.P.	Manhole station, with weir installed
L2	Land Use	Walsh Avenue, near SPRR	Santa Clara	Santa Clara	heavy industry	28	27" R.C.P.	Manhole station, with weir installed
L3	Land Use	Frances and Beamer streets, north of Sunnyvale Caltrans RR Station	Sunnyvale	Sunnyvale	commercial	265	42" R.C.P.	Manhole station, with weir installed
L4	Land Use	Hale Creek, near Magdalena Rd.	Santa Clara County	SCVWD	low-density single-family residential (hillside)	1,633	open channel	SCVWD gaging station No. 33
L5	Land Use	Sunnyvale East Channel, near Fremont Avenue	Sunnyvale	SCVWD	single-family residential (valley)	2,080	channelized	Highly-erodable channel, rating developed
L6	Land Use	Pasetta and Williams, near San Tomas Expressway and SPRR	Santa Clara	Santa Clara	multi-family residential	85	33" R.C.P.	Manhole station, with weir installed

Table ES-1. STATION DESCRIPTION (continued)

Designation	Type of Station	Location	Location	Jurisdiction	Principal Land Use	Drainage Area (acres)	Conveyance	Remarks
L7	Land Use	Stevens Creek, above Stevens Creek Reservoir	Santa Clara County	SCVWD	open (forest)	8,410	natural	Rating developed but not considered reliable because of backwater effects
L8	Land Use	Packwood Creek, at Jackson Ranch (east of Anderson Reservoir)	Santa Clara County	SCVWD	open (ranchland)	6,464	natural	SCVWD gaging station No. 57
S1	Stream	Calabazas Creek, at Wilcox School	Santa Clara	SCVWD	mixed	9,216	natural	SCVWD gaging station No. 26A
S2	Stream	Sunnyvale East Channel, at Bayshore Frontage Road (A.P. Sta 2)	Sunnyvale	SCVWD	mixed	3,437	channelized	SCVWD gaging station No. 74
S3	Stream	Guadalupe River, at San Jose	San Jose	SCVWD	mixed	15,904	natural	USGS gaging station No. 169000
S4	Stream	Coyote Creek, at Montague	San Jose	SCVWD	mixed	79,552	natural	SCVWD high-flow gaging station No. 2060
R1	Reservoir Release	Below Stevens Creek Reservoir (A.P. Sta 14)	Santa Clara County	SCVWD	open	10,924	natural	SCVWD gaging station No. 44

Table ES-1. STATION DESCRIPTION (concluded)

Designation	Type of Station	Location	Location	Jurisdiction	Principal Land Use	Drainage Area (acres)	Conveyance	Remarks
R2	Reservoir Release	Below Lexington Reservoir	Santa Clara County	SCVWD	open	23,859	natural	SCVWD gaging station No. 67
R3	Reservoir Release	Below Guadalupe Reservoir	Santa Clara County	SCVWD	open	3,808	natural	SCVWD gaging station No. 17
R4	Reservoir Release	Below Almaden Reservoir	Santa Clara County	SCVWD	open	7,667	natural	SCVWD gaging station No. 16
R5	Reservoir Release	Below Calero Reservoir	Santa Clara County	SCVWD	open	4,621	natural	SCVWD gaging station No. 13
R6	Reservoir Release	Below Anderson Reservoir	Santa Clara County	SCVWD	open	124,787	natural	SCVWD gaging station No. 9

Water quality monitoring was conducted to characterize wet weather water quality, dry weather water quality, and reservoir release water quality. Wet weather water quality monitoring consisted of monitoring water quality at land use and stream stations for seven storm events. Flow composite samples were collected using automatic samplers. Dry weather water quality monitoring was conducted by collecting grab samples at the stream stations eight times throughout the program. One round of reservoir release water quality monitoring was conducted at seven stations immediately downstream of reservoirs.

Sediment monitoring was conducted at the four stream stations quarterly throughout the first year of the monitoring program. Samples were obtained during dry weather.

Bioassay testing was conducted to evaluate wet and dry weather toxicity as it might affect the freshwater tributaries to the Lower South Bay. Wet weather samples were obtained from land use and stream stations during three storms. Dry weather samples were obtained from stream stations on three occasions. Static renewal tests were conducted on "whole effluent" (i.e., no dilution) using three species: Ceriodaphnia dubia (an aquatic invertebrate), Pimephales promelas (fathead minnow), and Selenastrum capricornutum (a freshwater algae).

Analytical Suites

The chemical suite for water quality and sediment analyses (and the loads prediction) focused on potentially toxic contaminants, including heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc) and organics, including volatile and semi-volatile organics, and pesticides and herbicides. The analytical suite also included selected nutrients and bacteria. The study design called for sampling the first and sometimes the second round using a comprehensive analytical suite (complete suite) and then, based on the results of the initial sampling, using a more limited suite (reduced suite) for subsequent sampling rounds.

The sampling was conducted starting in February 1988 and ended in April 1989. Most of the wet weather and toxicity sampling was conducted in the winter of 1989.

Sampling Methods

The sampling methods for the wet weather sampling program utilized state-of-the-art automatic sampling equipment consisting of ISCO water quality samplers, a pressure transducer to measure stage, a data logging system, and a microprocessor with software to control the sampling system. The system was designed so that sampling was initiated automatically based on stage. Once initiated, the sampler was programmed to obtain twenty discrete 500 ml samples throughout the runoff event at intervals corresponding to a given runoff sampling volume equal to one-twentieth of the expected runoff at that station. The intended result was to obtain a 10-liter water sample which would represent the flow composite concentration. Prior to sampling, water depth-flow relationships (or rating curves) were developed for each station. Dry weather and sediment sampling was conducted using grab methods. The water used in the laboratory toxicity testing utilized the flow composite sample in the wet weather tests, and discrete daily grabs in the dry weather tests. The toxicity tests themselves followed EPA guidelines on short-term methods for estimating acute and chronic toxicity in freshwater.

Quality Assurance and Quality Control

A comprehensive quality assurance and quality control program was followed to evaluate the quality and reliability of the field sampling and laboratory analytical programs. The program elements consisted of the use of external reference standards which were submitted to the laboratories as "blind samples," field duplicates, laboratory replicates, and laboratory matrix spike duplicates. The number of quality assurance samples was approximately 10 percent of the total number of samples analyzed.

SCOPE OF DATA ANALYSIS AND WATERSHED MODELING

All data were stored and manipulated on computer spreadsheet and/or relational data bases that facilitated the integration and evaluation of hydrologic, water quality, and toxicity testing results. Standard statistical analytical techniques were used to characterize the observed variability in hydrologic and water quality data. Log-normal distributions were often used for this purpose. Parametric and non-parametric statistical methods were used to assist in the evaluation of whether differences in observed water quality between stations were significant. Such tests were used to supplement judgment and observed trends.

The watershed loads model utilized EPA's Stormwater Management Model (SWMM) to estimate annual runoff volumes from each of the eleven watersheds (see above) and used the measured data to estimate the mean annual water quality of this runoff. The product of the two is the estimated annual load.

The SWMM modeling required subdivision of the watersheds into subcatchments which took into account spatial variations in rainfall, land use, topography, and soil conditions. The model was run using a 15-minute time step to predict the continuous runoff response for each storm event and for each subcatchment. Annual runoff was estimated as the sum of the predicted storm event runoffs for each year. Hydrologic calibration and verification were conducted using the 1974-1989 historical rainfall records.

The water quality associated with the runoff from each subcatchment was estimated based on the observed water quality from stations whose land use was representative of the land use in that subcatchment. Thus loads could be predicted from each subcatchment and summed to estimate the total watershed load or the load at any downstream location. Predicted versus observed loads were compared at the four downstream monitoring stations to develop "correction factors" that were applied to the estimated mean water quality data as determined from the land use stations.

Using the above methodology, annual pollutant loads for heavy metals were predicted for the 1974-1989 period. Dry weather loads and loads associated with reservoir releases (during very wet years when the reservoir storage were near capacity) were also estimated for this period and added to the wet weather load to estimate the total nonpoint source load. The total annual nonpoint source loads were then compared to the estimated loads from the three wastewater treatment plants (San Jose/Santa Clara, Sunnyvale, and Palo Alto) which discharge to the Lower South Bay.

RESULTS FOR HEAVY METALS WATER QUALITY DATA

Characterizing the Variability of Wet Weather Data

The flow composite or event mean concentration (EMC) observed at the various land use sampling stations showed a large degree of variability. An example of this variability for total suspended solids (TSS) is shown in Figure ES-1 for the land use stations. The variability is such that data from most stations tend to overlap and it was not possible to reliably distinguish differences in water quality amongst the residential and commercial land uses. The result is that we chose to pool the residential and commercial data together and characterize runoff water quality based on three classifications of land use: open, residential/commercial, and heavy industry. Median and mean estimates of water quality for these land use categories were then estimated based on a log-normal representation as shown in Figure ES-2 for the pooled copper and nickel data.

Levels of Total Metals Concentrations

Heavy metals were usually measured as totals, in contrast to dissolved. Of the ten metals in the analytical suite (see above), six metals were consistently present in detectable concentrations (cadmium, chromium, copper, lead, nickel and zinc). Arsenic, selenium, silver, and

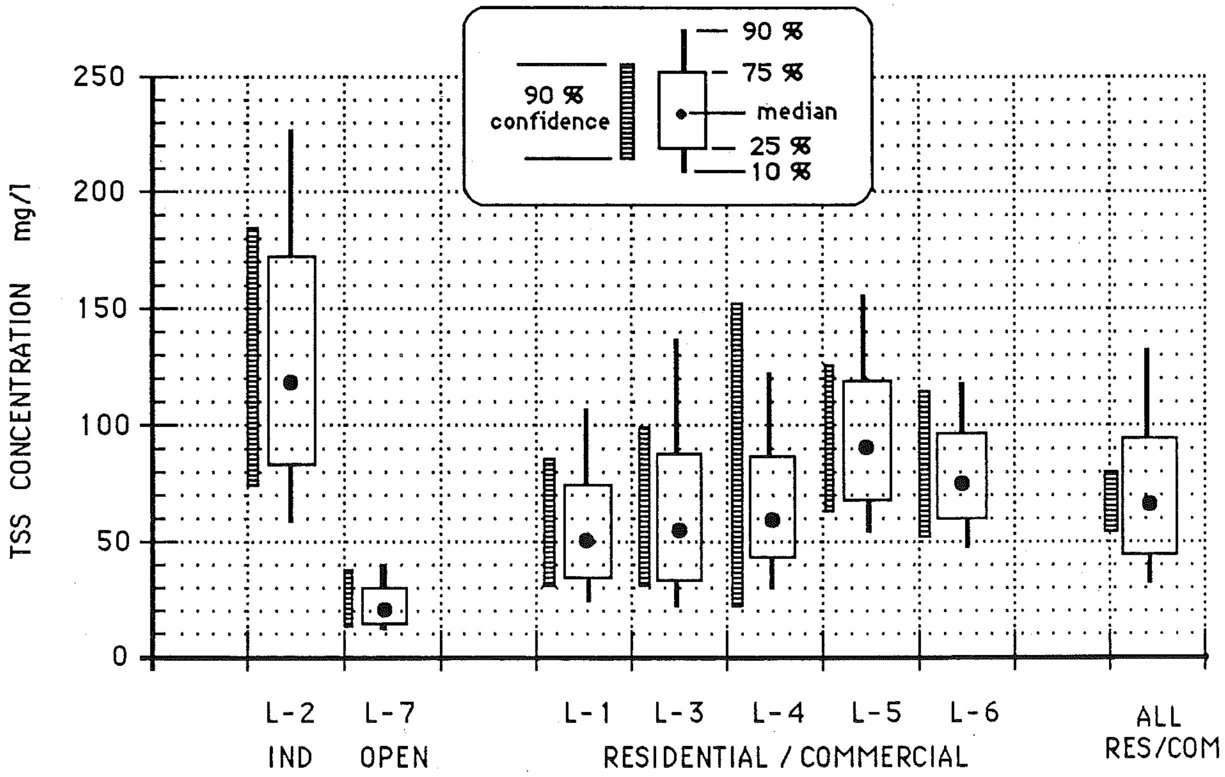
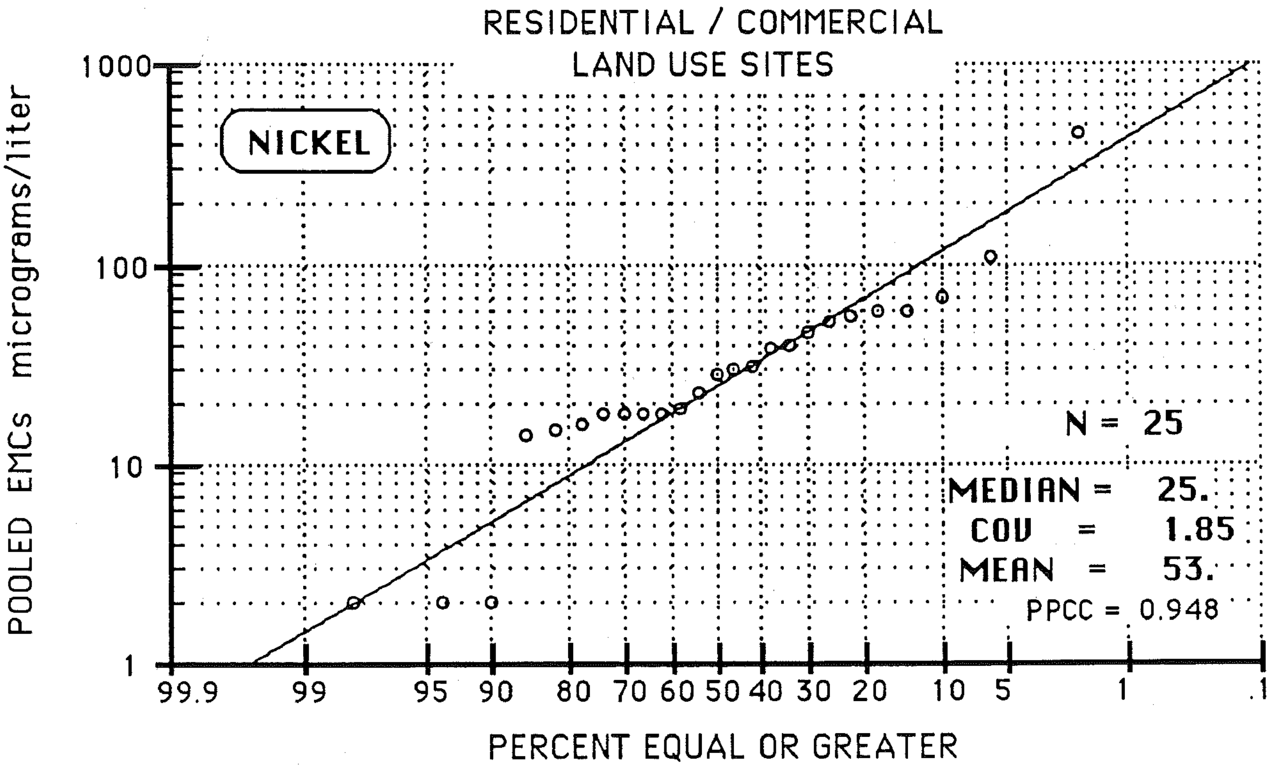


Figure ES-1. Box Plot Comparison of TSS Concentrations from Land Use Sites



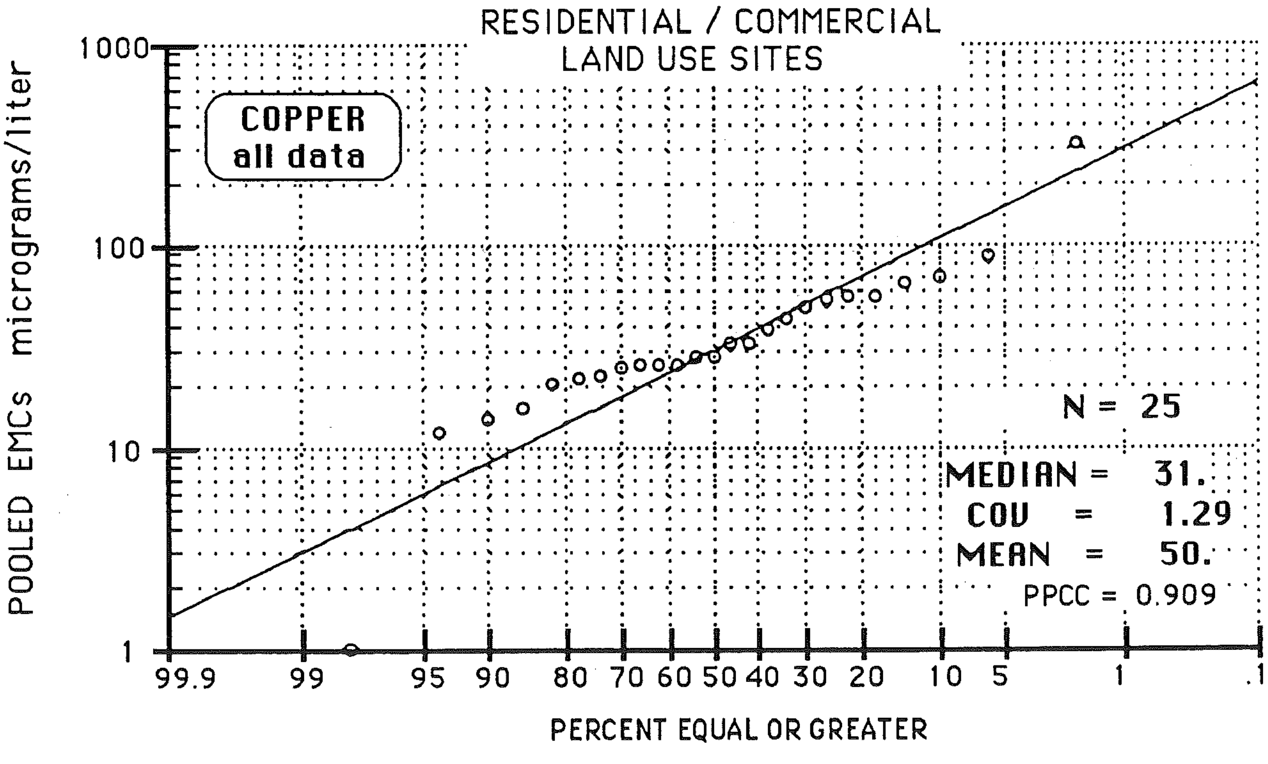


Figure ES-2. Nickel and Copper Concentrations in Measured Storm Events at Residential / Commercial Land Use Sites.

mercury were usually undetected. The pollutants can be classified into three groups based on the levels of concentration. Cadmium concentrations are always the lowest, zinc concentrations are usually the highest, and the remaining metals concentrations are similar and lie between cadmium and zinc. A summary of the median concentrations for these metals is shown in Table ES-1 for individual and pooled stations. Very consistent patterns emerge from this table.

Clearly the dry weather metals concentrations (0.3-10 ppb) in the streams were generally the lowest observed and below or comparable to data collected at the open land use site or at the stations below the reservoirs. Thus, dry weather sources are not an important component of the total nonpoint source load and control of such sources would not be cost-effective.

Background wet weather metals concentrations are best characterized by the open land use data which are similarly quite low (0.5-8 ppb). To the extent that these data (which are from only one site) are representative of open areas in general, it can be said that before development (urban and agricultural) in the Valley, metals loads to the Bay were low, relative to what they are today.

Wet weather metals concentrations from the residential and commercial land use catchments are substantially larger than concentrations from dry weather, reservoir release, and the wet weather open stations. For example, the median copper concentration from the pooled residential/commercial sites is 31 ppb compared to concentrations at the open land use site of 6 ppb.

Wet weather metals concentrations from stream stations were generally higher than concentrations at the residential/commercial land use stations. For example, the median copper concentration at the pooled stream stations was 55 ppb compared to 31 ppb at the pooled residential/commercial stations. Thus, there appear to be additional sources of pollutants which seem to accumulate in stream sediments and which are mobilized during storm events, especially early season events.

Wet weather metals data from the industrial land use site are generally the highest observed. For example, the cadmium concentration is 5.5 ppb, compared to 1.3 ppb at the pooled residential/commercial sites, and 0.5 ppb at the open site. Lead and zinc are similarly high compared to other stations.

Soluble Fraction of Trace Metals

In stormwater runoff there are generally high levels of suspended sediment to which pollutants are adsorbed. Thus, the total pollutant concentration consists of the adsorbed fraction and the soluble fraction. Soluble fractions were measured in two storm events.

Dissolved copper generally ranged between 5-25 percent at the land use and stream stations. Copper was mostly in the dissolved form (soluble fractions equal to 82 and 100 percent) at the open station (Station L7) which sampled a heavily forested catchment. The dissolved fraction of lead was small, generally less than 5 percent. Nickel in the dissolved form ranged between about 5 to 15 percent, and zinc between about 30 to 50 percent. Dissolved fractions of cadmium were often below detection levels (0.2 ppb) and generally less than 25 percent of total. Dissolve chromium ranged between about 1 and 20 percent of total. Arsenic, mercury, selenium, and silver were usually undetected.

Exceedances of EPA Toxic Criteria

To evaluate the potential toxic effect of the observed concentration levels, data were compared with EPA aquatic life toxic criteria. As the duration of typical stormwater runoff events is measured in hours, it appeared most reasonable that the wet weather data be compared with acute criteria and dry weather data be compared with chronic criteria. As the criteria are designed to protect aquatic life as exists in the streams, the exceedances at the stream stations are the most pertinent. At the stream stations, total copper exceeded the criteria 21 of 24 times (90 percent of samples) during wet weather and in 1 of 26 dry weather samples. Lead, zinc, and cadmium each exceeded the criteria between 3 and 4 times during wet weather (about 17 percent of samples); whereas there was only one dry weather exceedance, and that was for zinc. No dry or wet weather exceedances were recorded for nickel, arsenic, chromium, mercury, selenium, or silver.

If the same comparison is conducted using estimated soluble fractions, the exceedances of copper at stream stations is reduced to about 4 of the 24 wet weather samples (about 17 percent) and the exceedances of the other pollutants are eliminated.

EPA toxic criteria are developed to be compared with the "acid soluble" fraction which is neither the total or dissolved fraction, and thus the exceedances described above for total and soluble fractions bracket the "true" estimate that would be based on the acid soluble fraction.

RESULTS FOR ORGANICS WATER QUALITY DATA

Pesticides and Herbicides

Organochlorine pesticides were detected in 14 of 50 wet weather samples (about 30 percent) and in none of 26 dry weather samples. The compounds identified were DDE (6 detections), DDT (5), alpha-BHC (4), gamma-BHC (3), gamma-chlordane (3), total PCB (3), alpha-chlordane (2), DDD(1), and endosulfan (3). All concentrations were at trace levels and ranged between about 0.1 to 1.4 ppb.

Chlorinated herbicides were undetected in all 17 wet weather samples, but were detected in 3 of 18 (about 20 percent) dry weather samples. The compounds detected were 2,4-D (3 samples) and Dicamba (2 samples). The concentrations ranged from about 5 to 60 ppb.

Volatile Organics

Volatile organics were detected in 5 of 18 wet weather samples (about 30 percent) and in 1 of 4 dry weather samples. Compounds detected in the wet weather samples were total xylene (2 detections), methylene chloride (1), acetone (1), and 2-butanone (1). The dry weather sample contained TCE. The concentrations ranged between about 10 to 130 ppb. Acetone was also measured in a laboratory blank and thus the acetone detection is likely related to laboratory contamination. The methylene chloride and 2-butanone detects are also suspect.

Polynuclear Aromatic Hydrocarbons

Polynuclear aromatic hydrocarbons (PAHs) were detected in 14 of 50 (about 30 percent) wet weather samples and in 1 of 26 dry weather samples. The compounds detected were benzo(b)fluoranthene (12 samples), benzo(k)fluoranthene (6), fluoranthene (6), benzo(a)pyrene (4), pyrene (2), indeno pyrene (1), and benzo(a)anthracene (1). Concentrations ranged between about 0.1 to 3.3 ppb. The one dry weather sample in which PAHs were detected was analyzed to contain benzo(b)fluoranthene, benzo(k)fluoranthene, and benzo(a)pyrene.

The presence of PAHs in wet weather samples, estimated above at about 30 percent, is underestimated as most of the above detections were measured using EPA method 610 (detection limits of 0.2 to 2.0 ppb) which was used only after the first two storms. The method used in the first two storms was a less sensitive method, 625, where the detection limit is only less than 10 ppb.

Exceedances of Toxic Criteria

Comparisons with EPA aquatic life criteria for those pollutants for which criteria have been developed (chlordane, DDT, DDD, DDE, PCBs, and Dicamba) indicated that measured concentrations were well below toxic criteria for all samples.

SEDIMENT QUALITY

Metals Data

The metals sediment data can be subdivided into two groups based on the level of concentration observed. Zinc, chromium, copper, lead, and nickel were consistently detected at levels between 30 and 200 mg/kg (ppm); whereas arsenic, cadmium, mercury, selenium, and silver concentrations were about an order of magnitude lower in concentration (0.1 to 7 ppm) or not detected at all. Zinc, copper, and lead concentrations correlated well with the total percent silt and clay at the stations. Resuspension of this fine-grain material in the streams during storm events is likely to be one of the important factors causing elevated water column concentrations of these same metals. Comparisons of these metal concentrations with levels reported for natural soils show that the ranges of metal concentrations found in all stream stations appear to be well within the ranges of natural levels.

Organics

Organics have a propensity to adsorb to the organic fraction of sediments and thus organic pollutants were often found in sediment samples. Organochlorine pesticides were detected in all 16 sediment samples. The organochlorine pesticides that were commonly detected included DDT (6.4-37 ppb) and degradation by-products, DDD (2-34 ppb) and DDE (2.4-26 ppb), alpha-chlordane (8-28 ppb) and gamma-chlordane (6-20 ppb), gamma-BHC (5-7.8 ppb), beta-endosulfan (3.4-9 ppb), and PCBs (140-183 ppb). These same organochlorine compounds were also observed in wet weather water quality samples.

PAH's were detected in 7 of 16 sediment samples. The commonly detected PAH compounds were benzo(b)fluoranthene (190-540 ppb), benzo(k)fluoranthene (100-270 ppb), benzo(a)anthracene (100-270 ppb), benzo(a)pyrene (200-490 ppb), fluoranthene (400-919 ppb), pyrene (350-570 ppb), and phenanthrene

(260-380 ppb). As with the water quality analyses, the number of detects of PAHs (7) is underestimated because of the higher detection limits of the analytical method (8270) used for the earlier sampler rounds. As with the organochlorine pesticides, there is a good correlation between PAH compounds found in the stream sediments and found in the water column during storm events.

TOXICITY TEST RESULTS

Wet Weather Samples

Three rounds of tests were conducted to evaluate the toxicity of storm water samples on Ceriodaphnia (a water flea), fathead minnows, and Selenastrum (a freshwater algae). In 22 of 27 tests (about 80 percent) water from land use and stream stations was acutely toxic to Ceriodaphnia. However, in three tests using water from the open land use station (station L7 is located in the Santa Cruz Mountains on Stevens Creek above Stevens Creek reservoir) all Ceriodaphnia survived. In the tests with fathead minnows, zero survivability was recorded in only 3 of 19 tests (about 15 percent) and significant weight loss was recorded in 12 of 19 tests (about 60 percent). In the tests with the Selenastrum, the cell density in 17 of the 29 tests (60 percent) was significantly lower than the control.

Dry Weather Samples

In the three rounds of tests using water from the stream stations obtained during dry weather, Ceriodaphnia survivability was significantly reduced in only 2 of 13 tests, and the survivability of fathead minnows was not significantly reduced in any of the 12 tests. Other effects measures were similarly low.

HYDROLOGY AND WATERSHED MODELING

Precipitation

Over 60 rainfall gages operate in Santa Clara Valley, of which 30 are continuous recording gages that record at 15-minute or 1-hour intervals. The continuous recording gages were used for evaluating storm event statistics and for modeling. The overall network density for recording gages is about 25 square miles per gage, which is considered quite adequate for modeling purposes. Since half of the recording gages were not operating prior to 1974, runoff modeling and load estimates were conducted using the 1974-1989 period of record.

There is significant spatial and temporal variability in rainfall in the county. Strong orographic effects are created by the Santa Cruz Mountains to the west and the Diablo Range to the east. The highest rainfall occurs in the Santa Cruz Mountains where the mean annual rainfall ranges up to 50 inches. In contrast, the mean annual rainfall on the Valley floor is about 13 inches. The temporal variability in annual rainfall as measured at the National Weather Service gage at the San Jose Airport is shown in Figure ES-3. As shown in this figure, monitoring for this study (water years 87-88 and 88-89) was conducted during periods of lower-than-average rainfall and there is a concern regarding how representative the hydrologic and water quality data obtained are.

The statistical characteristics of individual rainfall events were analyzed using the rainfall analysis computer program SYNOP. The results of this analysis for the Airport gage for the period 1948 to 1989 (41 years) are shown in Figure ES-4. This figure shows that the median storm event volume is about 0.5 inches and the mean volume 0.7 inches. The analysis also showed that on average there was 17 storm events per year with a mean duration of 31 hours. The average period between events was 10 days.

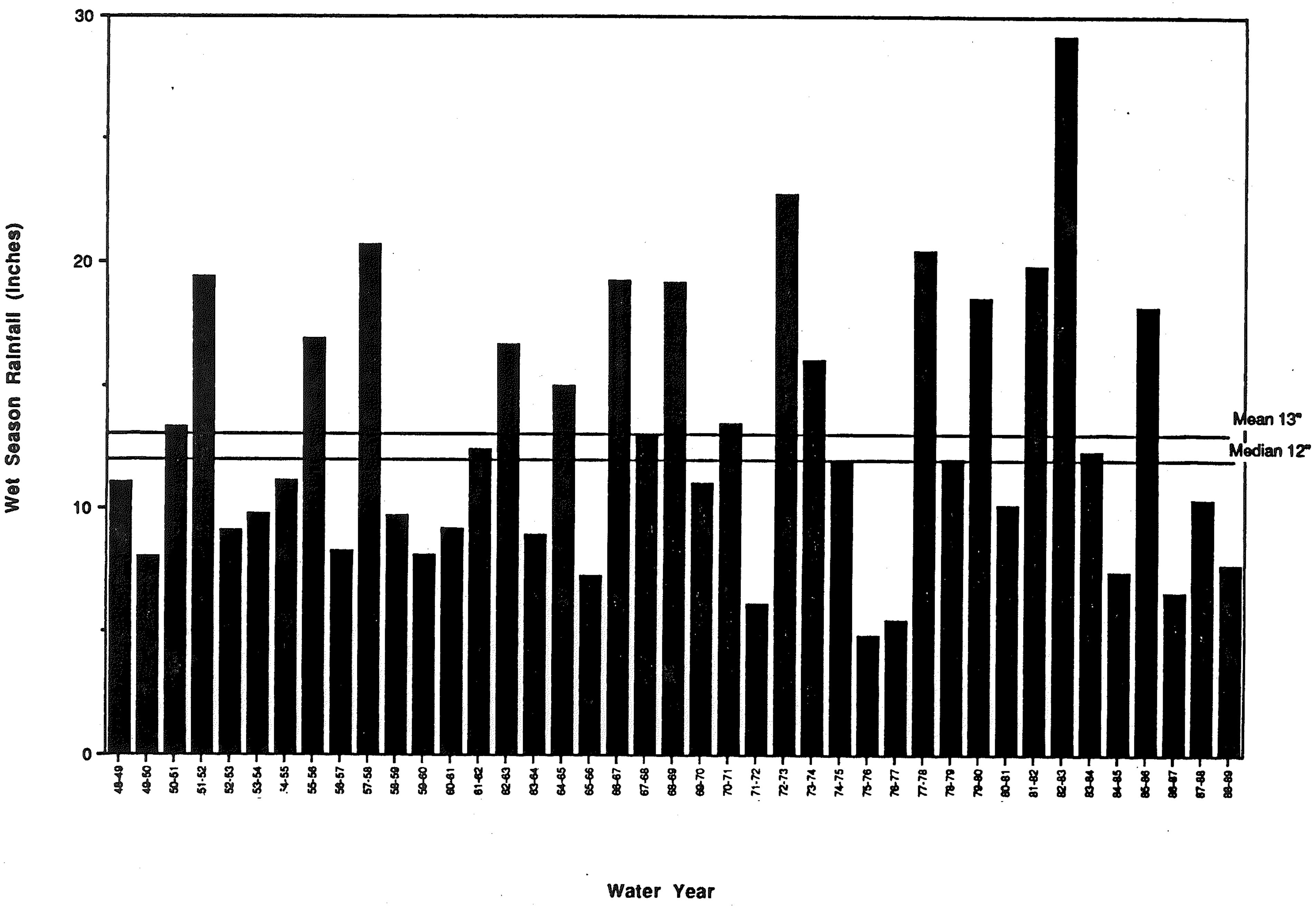


Figure ES-3. WET SEASON RAINFALL AT THE SAN JOSE NWS GAGE

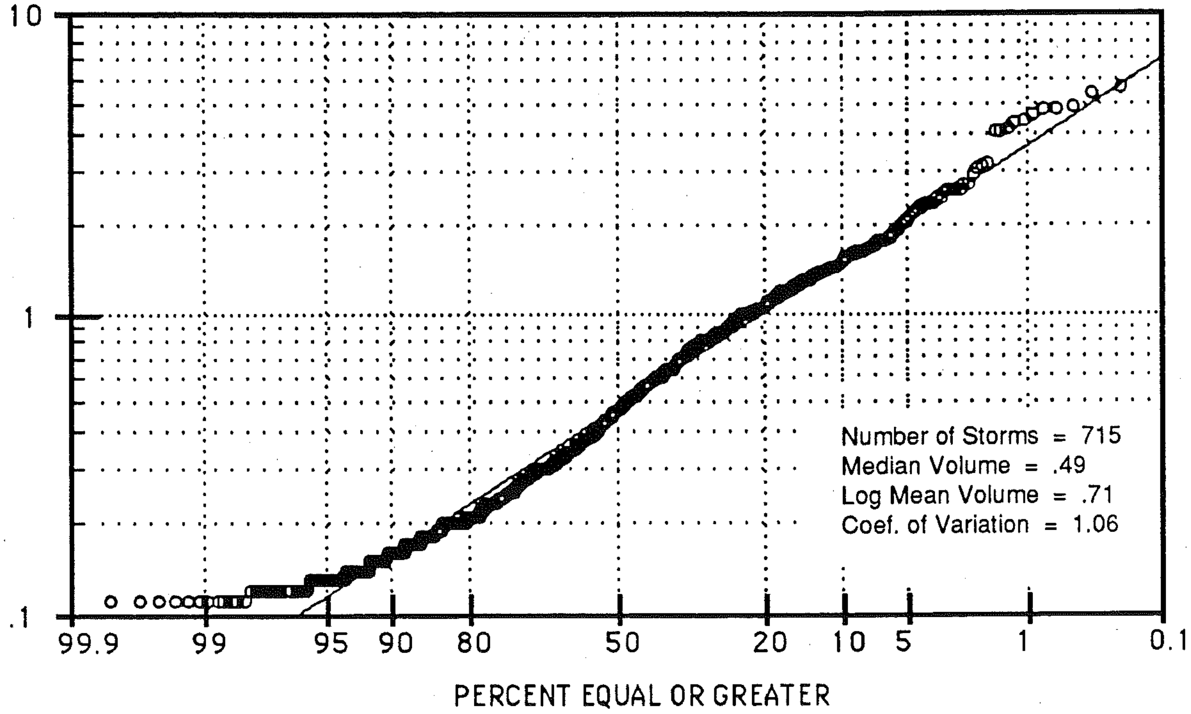


Figure ES-4. Log Probability Plot of Storm Volumes, San Jose NWS Gage

Compared to the historical record, annual precipitation during the years in which monitoring was conducted was 7.66 inches in water year 1988-89 and 10 inches in 1987-88. These values are 60 percent and 77 percent of the mean average of 13 inches, respectively. Average storm volume was also lower during the two monitoring years corresponding to 0.5 inches compared to 0.7 inches for the period of record. Moreover, the storms sampled tended to be smaller in volume; the average monitored storm volume was 0.36 inches.

Runoff

The SCVWD and the USGS operate a total of 39 recording streamflow gages in the county. Many of these gages, which date back as far as 1916, are used to assist the District in the operation of its reservoir storage and recharge system. The largest watershed monitored is the Guadalupe River, where a USGS gage monitors flows from a 146-square-mile catchment.

Like precipitation, annual runoff varies substantially from year to year as indicated by the Guadalupe flow record shown in Figure ES-5. During this study, a total of seven runoff events were monitored and these are shown in Figure ES-6 for the Guadalupe River Gage. This figure illustrates well the sparceness of storm events during the study period.

Watershed Hydrologic Modeling

As described above, as part of the loads modeling, the Stormwater Management Model was used to predict flows from ungaged watersheds. In order to calibrate the model, model predictions were compared with historical streamflow records previously discussed. The period of record used was from 1974 through 1989 as this period had a much denser rainfall network. The 15 years of record was usually divided into about two-thirds for calibration, and one-third for verification. Calibration was achieved by adjusting SWMM input parameters to best match the recorded storm event hydrographs. The most important parameters which were varied were the percent of impervious area in urban areas, and the hydraulic conductivity

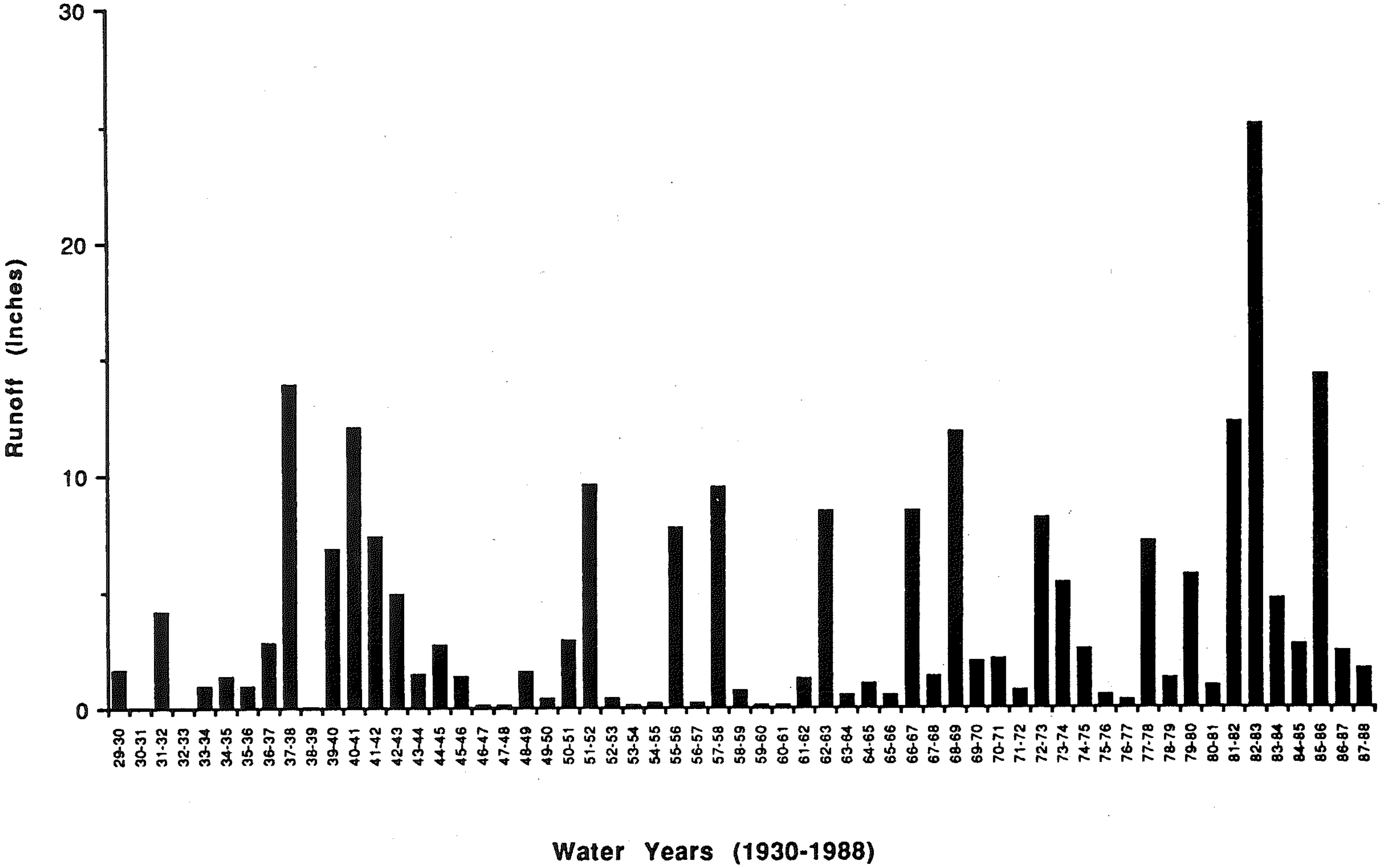


Figure ES-5. Annual Runoff at Guadalupe River Gage 11169000

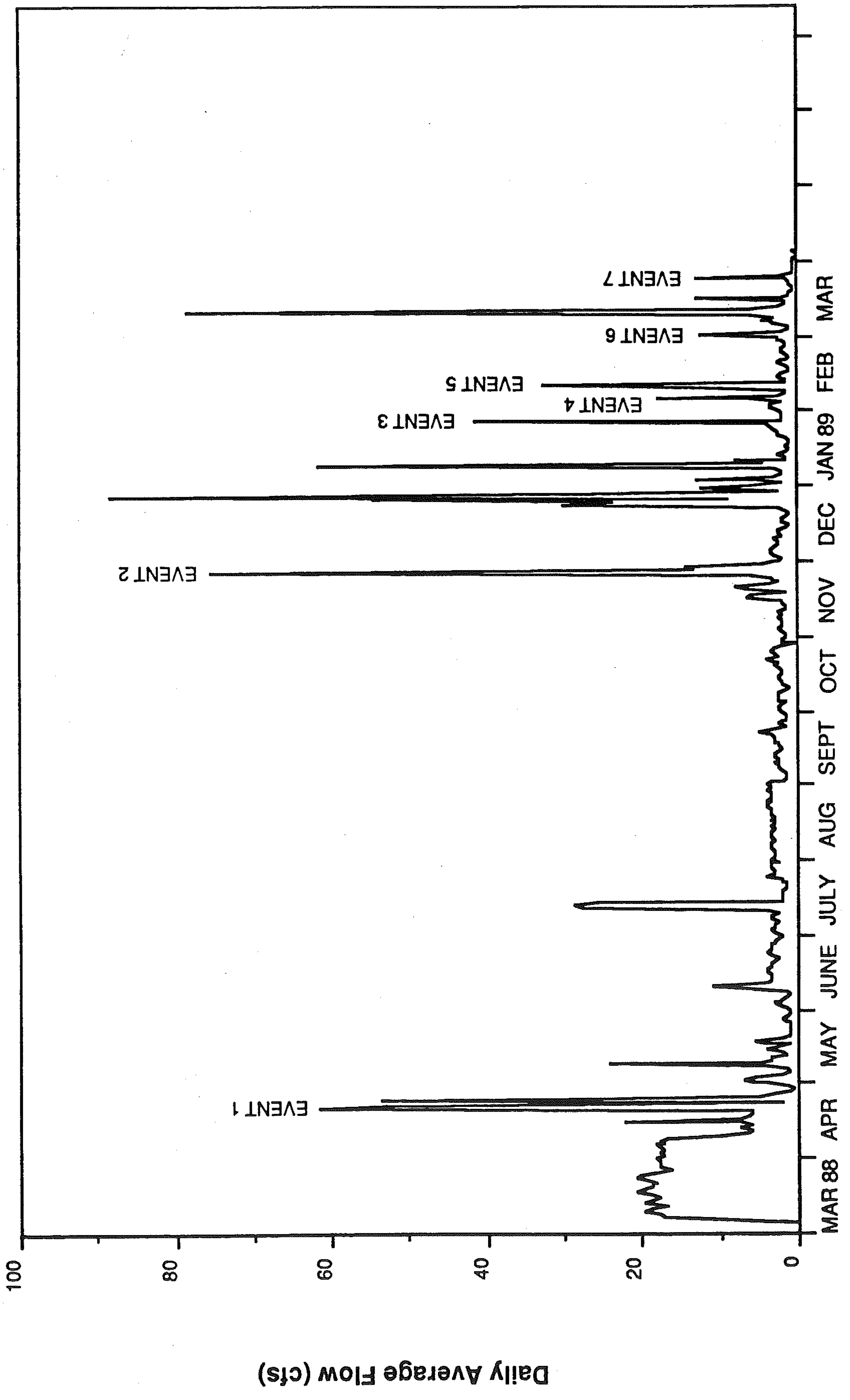


Figure ES-6. Guadalupe River Hydrograph for 1988-89 Sampling Period for infiltration in open areas. Other important parameters included the infiltration and soil moisture storage parameters, depression storage, and groundwater flow coefficients.

The quality of the calibration was measured by the root-mean-square error (RMSE) and bias of the measured and predicted wet season runoff volumes. (The wet season was defined as the period from September through March.) The calibration and verification results are shown in Table ES-2. Generally the RMSEs are quite low (10-20 percent) for the smaller watersheds (e.g., Calabazas Creek, Sunnyvale East Channel, Saratoga Creek, and San Tomas Creek) which are relatively simple watersheds and in which flow diversions are limited and well defined. The model was less accurate in predicting runoff from Stevens Creek, and had an RMSE of 34 percent for the combined calibration-verification period.

Calibration difficulties were encountered on the Guadalupe River where, during wet years and in the latter part of the wet season, it was necessary to estimate stormwater runoff as the difference between the measured total downstream flow and the upstream reservoir release flow. Stormwater runoff values so estimated appeared to be unreasonable and there is therefore some questions regarding the accuracy of the flow records. Calibration periods were therefore limited to dry periods when reservoir releases were negligible. In these conditions, the model was able to predict annual runoff volumes with an RMSE of 40 percent and a bias of -2 percent. The calibration of Coyote Creek was good, but this is because there was only 1 year of record at this station.

NONPOINT SOURCE LOAD ESTIMATES

Methodology

Annual load estimates for each of the 11 watersheds in the Study Area were made for the period of record 1977-1989 (11 years) to estimate the variability in loads associated with the variability in annual

Table ES-2. **Study Results - Trace Metals**

Site Median Concentrations (ug/L)

SITE	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Residential / Commercial Land Uses						
L-1	1.0	13	35	63	47	231
L-3	1.3	7	22	47	15	213
L-4	1.0	25	22	4	25	47
L-5	1.8	16	33	44	23	295
L-6	1.6	24	47	49	27	239
ALL Res/Com Sites (pooled data)	1.3	14	31	37	25	200
Industrial Land Use Site						
L-2	5.5	33	49	121	48	1324
Open Land Use Site						
L-7	0.5	8	6	2	8	7
Reservoir Releases	< 0.2	5	6	2	6	6
Stream Stations - WET WEATHER						
S-1	2.0	22	47	39	47	249
S-2	1.7	25	42	39	32	287
S-3	1.4	25	48	52	65	179
S-4	2.2	35	53	53	75	174
pool all	1.8	36	55	76	65	251
pool S1 and S2	1.8	33	48	66	49	245
Stream Stations - DRY WEATHER						
S-1	0.2	2	7	1	2	12
S-2	0.4	3	3	1	2	9
S-3	0.2	3	3	2	2	8
S-4	0.2	4	6	1	2	14
pool all	0.3	3	5	1	2	10
pool S1 and S2	0.3	2	5	1	2	10

precipitation. (The purpose of using a part of the historical record is not to make historical predictions of loads, but rather to make predictions based on current conditions (e.g., current land use) for a range of meteorological conditions.) This period of record includes the wettest year on record (1982-83) and some of the drier years of record, so the selected period does represent a wide range of conditions.

The total nonpoint source load estimate consisted of three components: the wet weather runoff load, the dry weather load, and the load associated with reservoir spillway releases during wet years.

For each watershed, annual dry weather loads were estimated as the product of the annual dry weather flow times the mean dry weather water quality. The annual dry weather flow was estimated taking into account, as approprate, permitted discharges, reservoir releases during dry weather, and natural baseflow. Mean dry weather water quality was estimated based on the pooled measured data for the four stream stations.

Wet weather loads were estimated for each watershed in a two step process. In step 1, wet weather loads were estimated for each single land use subcatchment as the product of the predicted runoff times the mean measured concentration for that land use (see above). In step 2, annual load estimates were made at the four stream stations for 1988-89 and compared with the estimated annual load based on flow and water quality measurements at that station. Based on this comparison, the mean concentration for each land use was adjusted to agree with the measured load.

A key assumption in the wet weather loading methodology is that the water quality data collected during the relatively dry monitoring period (1987-89) is representative of wetter years in the period of record used for making predictions (1977-89). There are no multi-year annual data reported in the literature to help evaluate the validity of this assumption, and the load estimates therefore must be interpreted with this qualification in mind.

Reservoir (spillway) release loads were simply estimated as the product of the measured annual wet weather release flows times the mean concentration of the pooled reservoir release water quality data.

Nonpoint Source Load Estimate Results

Load estimates were made for those constituents which were consistently measured at levels well above detection limits and which are of general environmental interest. These constituents were cadmium, chromium, copper, lead, nickel, zinc, nitrate nitrogen, total Kjeldahl nitrogen, total phosphate, BOD, and TSS. All metals loads are for total metals. Predicted total annual flows and loads and summary statistics for these constituents are shown in Table ES-3. The table shows that the flows and loads vary significantly from year to year, with the largest flows and loads corresponding to the 1982-1983 water year.

The annual variation in loads and the components that make up the total load are shown in Figure ES-7 using copper as an example. This figure shows that dry weather loads are small compared to the total and that loads associated with wet weather reservoir releases are similarly small except during extremely wet years when such loads can be as large as about 15 percent.

Comparison of Nonpoint Source Loads with Loads from Wastewater Treatment Plants

Frequency distributions of predicted annual flow and annual loads for cadmium, chromium, and copper are shown in Figure ES-8. Also shown in these figures are the comparable flows and loads as estimated for the three wastewater treatment plants for 1987 and 1988 that discharge into the Lower South Bay. These figures show that point source flows from the WWTPs are exceeded by nonpoint source runoff in about 20 percent of the years for

Table ES-3. SUMMARY OF SWMM CALIBRATION/VERIFICATION

			Calibration			Verification			Combined Calibration and Verification Period		
Watershed	Calibration Period	Verification Period	Mean Wet-Season Runoff (in.)	RMSE (%)	Bias (%)	Mean Wet-Season Runoff (in.)	RMSE (%)	Bias (%)	Mean Wet-Season Runoff (in.)	RMSE[a] (%)	Bias[b] (%)
Calabazas Creek	1976-80, 86-88	1980-83, 1984-85, 1988-1989	4.08	8	-5	5.51	13	6	4.73	11	1
Stevens Creek	1977-1981	1975-77, 1981-83	1.96	15	1	2.15	45	1	2.06	34	1
Sunnyvale East	1974-1982	1984-1989	5.66	6	3	3.31	3	-9	4.59	9	-1
Saratoga Creek	1974-1982	1982-1986	6.57	30	-8	11.98	13	10	8.19	22	0.1
San Tomas Aquinas Creek	1975-1981	1983-1987	6.58	17	-7	6.93	25	5	6.73	21	-2
Coyote Creek	1988-1989	None	0.73	1	-1	None	None	None	0.73	1	-1
Berryessa Creek	1974-1979	1980-1982	1.39	19	-12	4.69	25	16	2.49	29	6
Guadalupe River	1977-1981	1981-82, 1987-89	2.92	38	-2	1.73	40	-3	2.4	40	-2
STUDY AREA			2.80	25	-4	2.98	22	5	2.8	25	-1

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[a] RMSE measures the average error in predicted wet-season runoff, as a percentage of the mean wet-season runoff volume.

[b] BIAS measures the average bias (tendency to under- or over-predict) in predicted wet-season runoff, as a percentage of the mean wet-season runoff volume.

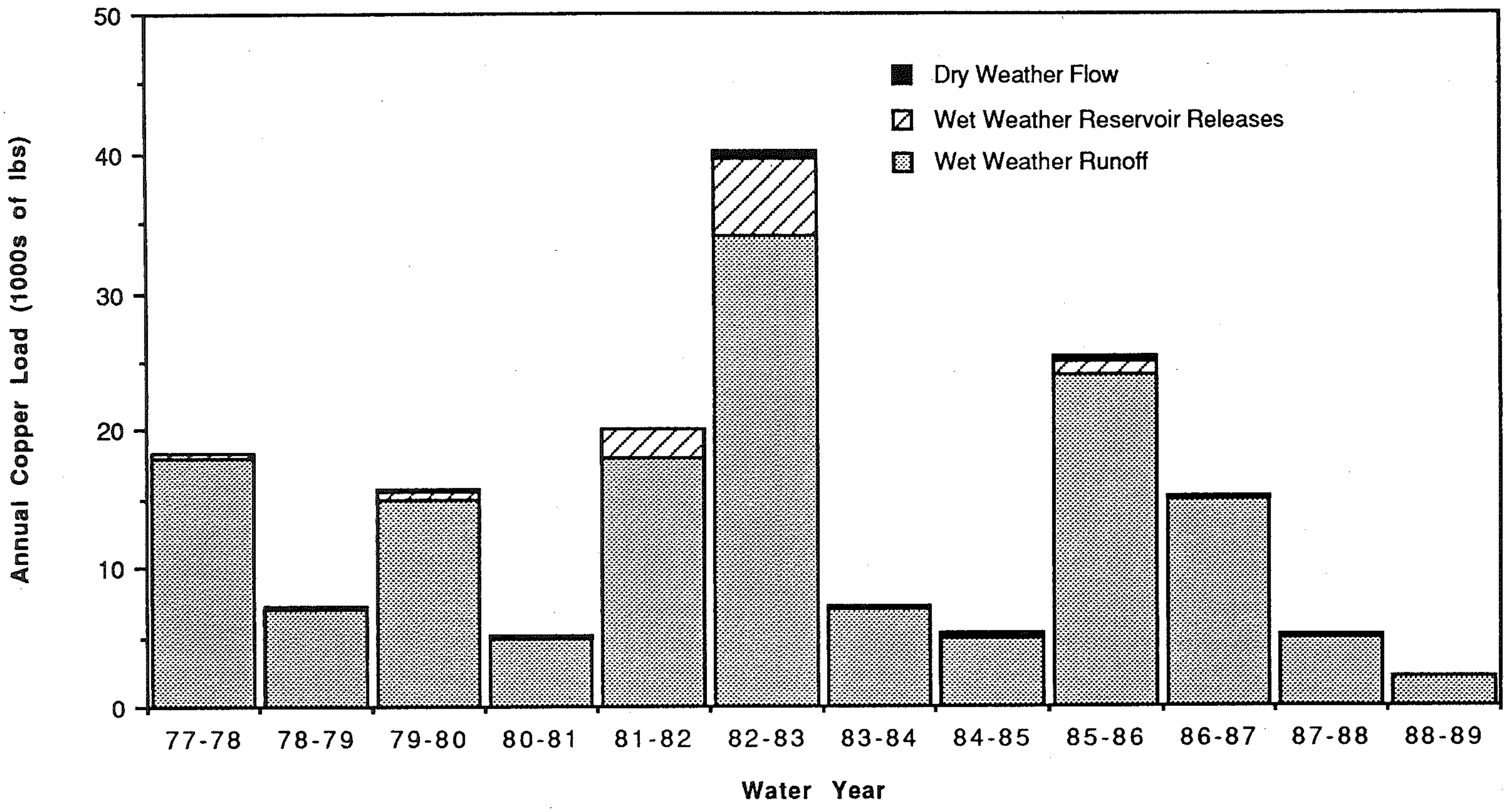


Figure ES-7. Time Series of Annual Total Nonpoint Source Load for Copper

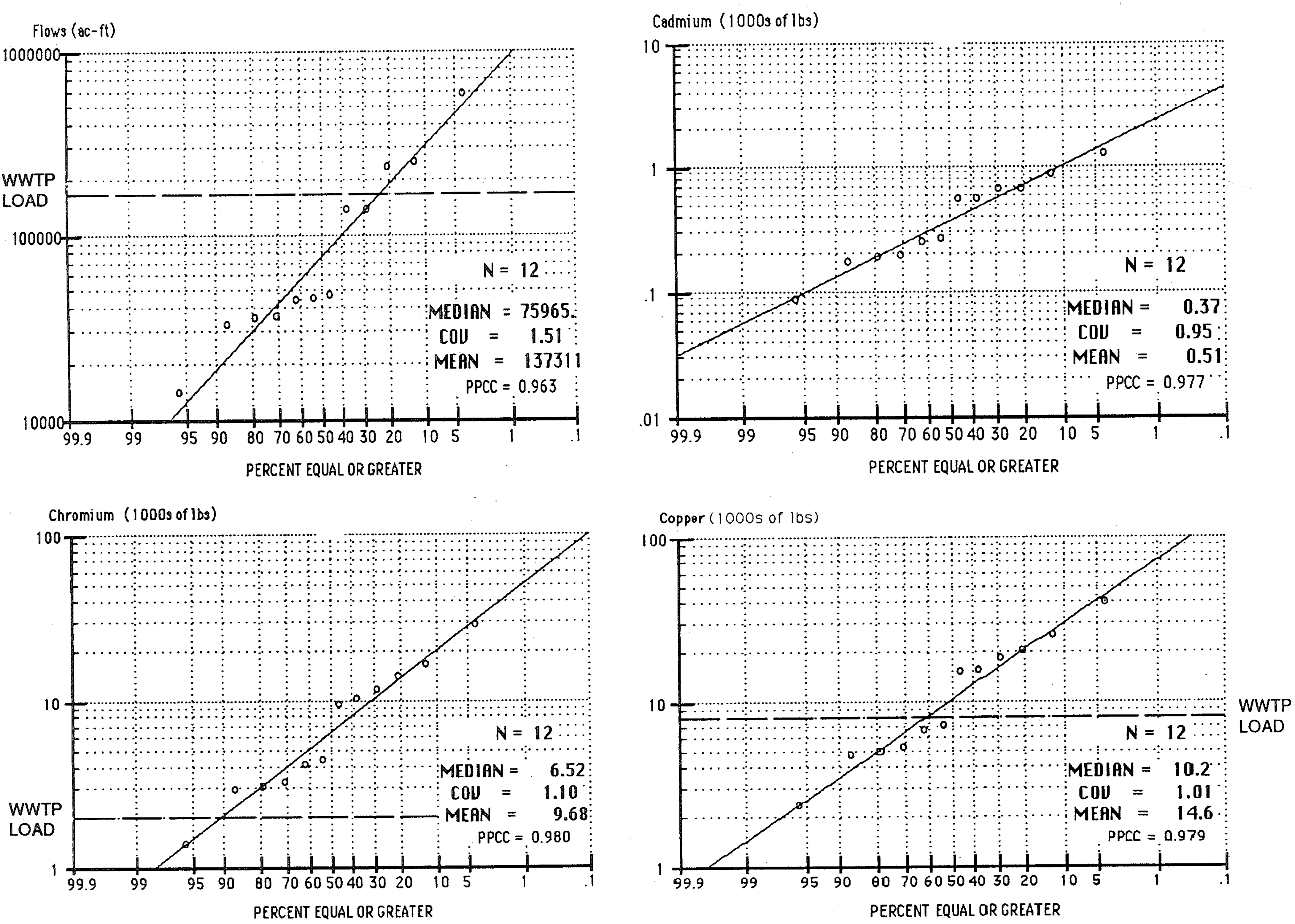


Figure ES-8. Frequency distributions of Annual Flows and Annual Loads for Cadmium, Chromium, and Copper which predictions were made. The point source copper load is exceeded by the nonpoint source load in approximately 60 percent of the years. Thus the importance of point versus nonpoint sources of flows and pollutants is very dependent on the annual rainfall.

The estimated mean annual flows and loads from point and nonpoint sources are given in Table ES-4. The percentage of the total load associated with each source is also given in Table ES-4. This table shows that mean annual metals loads from nonpoint sources tend to be somewhat higher than the mean annual WWTP load. Nutrient loads are primarily from the WWTPs, and the sediment load is primarily associated with nonpoint sources.

It should be pointed out that the metals comparison in Table ES-4 does not reflect the very different metals speciation between these two sources. Specifically, the high sediment load in nonpoint source runoff causes much of the metals loads to be adsorbed, whereas the metals in the WWTP effluent is substantially in the dissolved form. This difference in speciation may have major implications in the biological impact associated with these two source types.

Uncertainty in Loads Estimates

Uncertainty analysis was performed to assess the uncertainty in annual loads estimates due to uncertainty in (1) estimates of annual flow volumes, and (2) estimates of mean concentration. The uncertainty in annual flow volume estimates was quantified based on the SWMM model calibration errors. Uncertainty in mean concentration estimates was quantified based on the mean and variance of the water quality sampling data. A first-order, second moment uncertainty analysis was then used to derive the mean and variance of annual load estimates.

Results of the uncertainty analysis were expressed in terms of 90 percent confidence bounds about the annual load estimates. These bounds

Table ES-4 • Comparison of Average Annual Point Source versus Nonpoint Source Loads

	Flow (ac-ft)	Chromium (1000 lbs)	Copper (1000 lbs)	Lead (1000 lbs)	Nickel (1000 lbs)	Zinc (1000 lbs)	Nitrate (1000 lbs)	TKN (1000 lbs)	Phosphate (1000 lbs)	BOD (1000 lbs)	TSS (1000 lbs)
WWTP Load	180,000	2	8	8	12	28	8,700	1,500	8,700	2,000	1,300
NPS Load	140,000	10	15	15	21	50	206	378	161	2,100	69,000
Total Load	320,000	12	23	22	33	78	8,906	1,878	8,861	4,100	70,300
Percentage WWTP	56%	18%	36%	35%	37%	36%	98%	80%	98%	49%	2%
Percentage NPS	44%	82%	64%	65%	63%	64%	2%	20%	2%	51%	98%

define the region in which one is 90 percent confident the "true" value of load lies. For the mean annual load, confidence bounds were generally about plus or minus 50 percent away from the estimated mean annual load. For example, the 90 percent confidence bounds for the mean annual copper load indicate the true copper load lies between 8400 and 24,000 lbs, with a mean estimate of 14,600 lbs. Uncertainty in the load estimates for individual years was somewhat greater, with 90 percent confidence bounds about plus or minus 95 percent from the estimated value.

CONCLUSIONS

A comprehensive multi-year monitoring and modeling study was conducted to estimate the effects of nonpoint source runoff on pollutant loads entering the Lower South Bay and on water quality and toxicity in tributary streams entering the Bay. Unfortunately, the monitoring program was conducted during a drought period and results may be biased because of these conditions. With this qualification, the principal conclusions drawn from this study are as follows.

Water Quality - Metals

- Cadmium, chromium, copper, lead, nickel, and zinc were generally found in stormwater runoff in detectable concentrations. Arsenic, mercury, selenium, and silver were generally not detected. Limited sampling for hexavalent chrome showed no detections.

- Concentrations of metals in streams during wet weather generally were higher (by a factor of about 2) than at land use stations. Thus, it appears that resuspension of metals adsorbed to bottom sediment is an important process affecting water quality in streams. This is supported by relatively good correlations between water quality and suspended solids and observed metals levels in stream sediment samples.

- Distinct differences in wet weather water quality could only be observed between open, residential/commercial, and heavy industrial sites. Mean concentrations at the heavy industrial station tended to be two to three times values at commercial/residential sites for cadmium, chromium, lead, zinc, and TSS.

- At most land use and stream stations, the soluble fraction of heavy metals in stormwater runoff was measured as follows: copper (5-25 percent), lead (less than 5 percent), nickel (5-15 percent), zinc (30-50 percent), cadmium (less than 25 percent), and chromium (1-20 percent).

Water Quality - Organics

- During wet weather, organochlorine pesticides (DDE, DDT, etc.) and polynuclear aromatic hydrocarbons (PAHs) were each detected in about 25 percent of the samples. Volatile organics, organophosphorous pesticides, and chlorinated herbicides were seldom, if ever, detected.

- During dry weather, the only class of organics detected more than once was chlorinated herbicides (2,4-D and Dicamba).

Toxicity

- During wet weather and using total metals, EPA aquatic life toxic criteria were generally exceeded by copper, and occasionally exceeded by zinc, lead, and cadmium. Exceedances using the dissolved fraction of metals were substantially reduced to only a few exceedances for copper.

- During dry weather, EPA criteria were generally not exceeded.

- Wet weather samples were found to have a significant effect in about 80 per cent of the laboratory toxicity tests. In contrast, dry weather samples showed toxicity effects in only 2 of 13 tests (15 percent).

Loads

- The estimated annual nonpoint source loads are highly variable from year to year. The highest loads were estimated for the 1982-83 water year, which had the highest runoff flows of record, approximately corresponding to the 100-year return period.

- The principal source of nonpoint source flows and metals loads is stormwater runoff. Dry weather sources are negligible (less than 5 percent). Reservoir release sources during very wet years account for about 15 per cent of the total nonpoint source flows and loads.

- When compared to the mean annual loads from the three WWTPs that discharge into the Lower South Bay, the nonpoint sources account for 60 to 80 per cent of the load for chromium, copper, lead, nickel, and zinc and about 98 percent of the TSS. The WWTPs account for 98 percent of the nutrients. Both sources have comparable BOD loads.

- In any given year, the importance of point versus nonpoint source loads will depend on the annual rainfall. For example, for the 11 years of record examined, the point source flows were exceeded by the nonpoint sources in about 20 percent of the years. The point source load for various metals were exceeded by the nonpoint source load as follows: chromium (90 percent), copper (60 percent) lead (60 percent), nickel (60 percent), zinc (60 percent).

SECTION 1

1.0
INTRODUCTION

1.1 BACKGROUND

San Francisco Bay can be subdivided into the North Bay, Central Bay, and South Bay (the latter being south of the Bay Bridge). The South Bay tends to be poorly flushed because of its semi-enclosed geometry and the relatively low tributary flows. Water quality problems have been aggravated by this condition, particularly in the Lower South Bay (south of Dumbarton Bridge).

The Regional Water Quality Control Board (Regional Board) has been conducting an active program in the Lower South Bay to evaluate the effects of the three major point source dischargers, namely the San Jose/Santa Clara, Sunnyvale, and Palo Alto wastewater treatment plants. As part of this program, a 5-year monitoring study (conducted by Kinnetic Laboratories, Inc., and Larry Walker Associates 1987) was performed for the South Bay Dischargers Authority (SBDA) between 1981 and 1986. The study found that increases in trace metals in the Lower South Bay did not correlate with mass emissions from the point source discharges, and it was suggested that stormwater runoff from urbanized areas could be a contributing factor.

Because of the water quality problems, the State Water Resources Control Board included the South Bay in its 304(L) list of impaired waters and in addition to the three point source discharges, have included the South Bay storm drains as a point source requiring an individual control strategy. To assist with developing a comprehensive control strategy, a waste load allocation study is scheduled to be performed.

Recognizing the potential role of nonpoint sources in the Lower South Bay, the Regional Board, in their 1986 Water Quality Control Plan for the San Francisco Bay Basin (Basin Plan), called for a detailed Action Plan to be submitted in the summer of 1987, to (1) conduct dry- and wet-weather water quality monitoring "for the evaluation of both concentrations of pollutants as well as total pollutant loadings and comparison with waste loads from point source discharges," and (2) "to identify and evaluate the effectiveness of additional nonpoint source pollution control measures." (These requirements are fulfilled by Volumes I and II, respectively, of our report.)

In response to the Regional Board's directive, the Santa Clara Valley Water District (SCVWD), the County of Santa Clara, and the municipalities of Campbell, Cupertino, Los Altos, Los Altos Hills, Los Gatos, Milpitas, Monte Sereno, Mountain View, Palo Alto, San Jose, Santa Clara, Saratoga, and Sunnyvale arranged a cooperative agreement to fund the program. The administration of the program was conducted by an NPS Task Force selected to represent the participants. The consultant contracts were managed by the SCVWD.

An Action Plan describing the scope of work for the program was developed by CH2M-HILL and EOA, Inc. (1987), submitted to the Regional Board, and approved in July 1987. In October of that year, the SCVWD contracted with Woodward-Clyde Consultants (WCC), in association with Kinnetic Laboratories, Inc., to implement the Action Plan by conducting what is popularly referred to as the "Santa Clara Valley Nonpoint Source Study."

From October 1987 through July 1989, Woodward-Clyde, Kinnetic Laboratories, the members of the NPS Task Force, and representatives for various South Bay municipalities and the county have worked together to conduct the studies required to satisfy the Regional Board's directives.

Two reports address the Basin Plan requirements. This report, Volume I, the Loads Assessment Report, focuses on the estimation of NPS loads based upon the results of the field sampling and watershed modeling efforts. Volume II evaluates the effectiveness of additional nonpoint source pollution control measures.

1.2 PURPOSE

The overall objective of Volume I is to characterize the nonpoint source pollutant concentrations and annual mass loads entering the Lower South Bay from Santa Clara County. These data, in combination with corresponding point source loading information, provide a loadings basis for the selection and implementation of appropriate control measures. As previously discussed, these data will also be ultimately used in a Waste Load Allocation analysis, which will eventually provide a means of making the essential link between load reduction and achievement of improved water quality and beneficial uses. Presumably, future implementation of capital-intensive treatment-based controls for nonpoint sources would be based on the Waste Load Allocation evaluation.

A secondary objective of this volume is to evaluate the effects of nonpoint sources on the tributary streams in Santa Clara County that enter the Lower South Bay. This evaluation included wet- and dry-weather toxicity testing, as well as analysis for many specific pollutants.

The overall objective of Volume II is to take the information developed in Volume I to assist in the evaluation of control measures and thereby address item (2) of the Regional Board's requirements.

1.3 GENERAL APPROACH AND ORGANIZATION OF THIS REPORT

The ultimate objective of this volume is to estimate annual pollutant loads entering the Lower South Bay from the tributary watersheds in Santa

Clara County. Load is the product of flow times concentration; thus there is a hydrologic and water quality component to estimating loads. The overall approach involved utilized the Stormwater Management Model (SWMM) for the hydrologic component. Calibration and verification of the model utilized historical precipitation and streamflow data collected by the SCVWD and the USGS. The water quality component was based on an analysis of the water quality data collected in this study.

This report is organized to develop, in a systematic way, the basis for estimating loads. Section 2.0 describes the Study Area. Section 3.0 summarizes past local and regional studies to provide a perspective on other data sources and what is already known regarding nonpoint source pollution in the area. The scope of the field sampling and laboratory analytical program is summarized in Section 4.0. Section 5.0 evaluates and analyzes existing hydrologic data and summarizes the hydrologic modeling efforts. The water quality data are analyzed in Section 6.0 and based on this analysis, best estimates of annual mean runoff water quality are made. Section 7.0 describes the results of the toxicity tests conducted to characterize the toxicity of the wet- and dry-weather flows.

Insights from the interpretation of the water quality data and hydrologic data lead to the formulation of the loading estimate methodology described in Section 8.0. Section 9.0 provides conclusions.

Appendix A provides a detailed description of the Field Program. Appendix B discusses the modeling approach and the model calibration and verification. Appendices C through F are concerned with the data. Appendix C interprets the results of the quality assurance/quality control (QA/QC) program and evaluates the quality of the data. Appendix D is a tabular summary of the water and sediment quality data collected. Appendix E is a summary of the toxicity data. Appendix F is a summary of the data collected by the ongoing USGS/SCVWD monitoring program. Appendix G summarizes the data from the point source Wastewater Treatment Plants and the estimates of annual loads based on these data. Appendix H summarizes the results of the analysis to quantify the uncertainty in the loads estimates.

SECTION 2

2.0
DESCRIPTION OF THE STUDY AREA

This section describes relevant features of the Study Area (e.g., land use, meteorology). More detailed information on specific topics such as hydrology is provided in later sections.

2.1 INTRODUCTION

Santa Clara County is located at the south end of the San Francisco Bay (Figure 2-1). It has a population of approximately 1.4 million people. The largest cities include San Jose (with a population of about 800,000), Sunnyvale (120,000), and Santa Clara (94,000). Figure 2-2 shows the various political jurisdictions. The County's employment is closely tied to the electronics and computer industries located in what is referred to as Silicon Valley. The Association of Bay Area Governments (ABAG 1987) forecasts that by 1990 almost 30 percent of all jobs within the nine-county San Francisco Bay Area will be in this county. By the year 2005, the population is projected to be about 1.6 million people, with most of the growth projected for the Gilroy-Morgan Hill areas (ABAG 1987).

2.2 TOPOGRAPHY AND LAND USE

The Study Area is defined as that portion of Santa Clara County that drains into the Lower South Bay (see Figure 2-3) (in packet). The area is approximately 690 square miles and consists of the relatively flat Santa Clara Valley, which is bordered by the Santa Cruz Mountains on the west and the Diablo Range on the east. The Santa Cruz Mountains are forested and steep, whereas the Diablo Range tends to be open grasslands with oak and

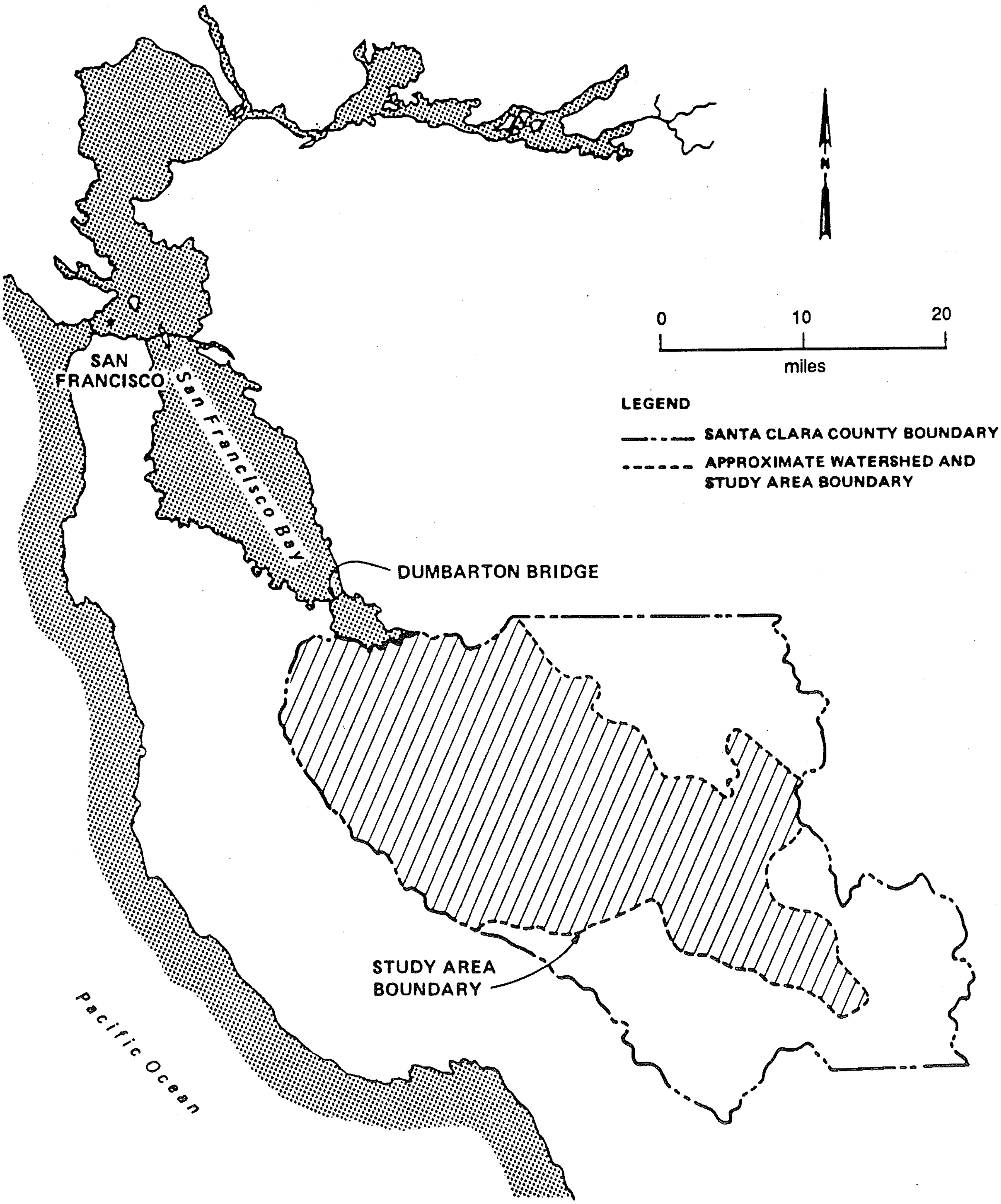
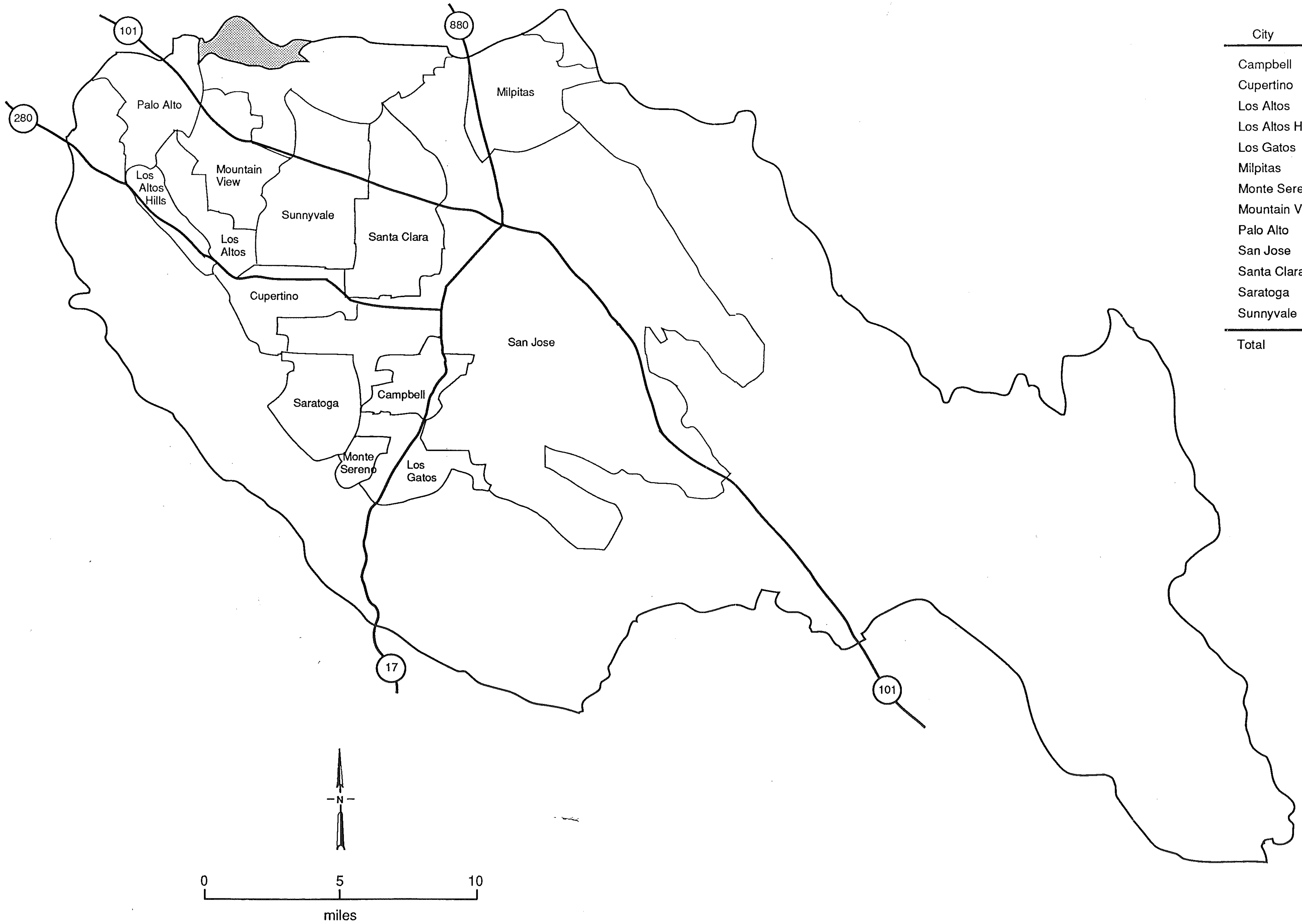


Figure 2-1. STUDY AREA LOCATION



City	Approx. 1990 Population	Approx. % of Total
Campbell	37,000	3
Cupertino	51,000	4
Los Altos	30,000	2
Los Altos Hills	10,000	1
Los Gatos	32,000	2
Milpitas	50,000	4
Monte Sereno	4,000	0.3
Mountain View	68,000	5
Palo Alto	68,000	5
San Jose	806,000	58
Santa Clara	95,000	7
Saratoga	31,000	2
Sunnyvale	119,000	8
Total	1,401,000	

Figure 2-2. POLITICAL JURISDICTIONS

pine. Peaks in these mountain ranges generally vary between 2000 and 3000 feet in elevation.

Most urbanization is located on the valley floor, except for some residential and commercial areas located in the foothills. Approximately 30 percent of the overall Study Area is residential. Industry, which makes up about 5 percent of the Study Area, is predominantly light industry associated with high-technology manufacturing. Approximately 62 percent of the Study Area is open. Most of the open area is in the upland portions of the watersheds. In watersheds that have upland reservoirs, much of the open area is above these reservoirs.

2.3 PRECIPITATION

Most of the precipitation in Santa Clara County occurs from October through April and is associated with moist winter storms advected from the west. This directionality, combined with orographic effects associated with the Santa Cruz Mountains and the Diablo Range, causes significant spatial variations in rainfall, as shown in Figure 2-4. For example, mean annual rainfall at Mt. Umunhum (elev. 3000 feet) in the Santa Cruz Mountains is 42 inches, whereas mean annual rainfall at the San Jose Airport gage (elev. 92 feet) is only 14 inches. At Mt. Hamilton (elev. 4070 feet) in the Diablo Range, the mean annual rainfall is 31 inches.

2.4 HYDROLOGY

The Study Area was divided into 11 watersheds (Figure 2-5). These are the Coyote Creek watershed on the east side of the valley, the Guadalupe River watershed, which drains the south-central portion of the valley, and a series of small, relatively urbanized watersheds that drain the west side of the valley.

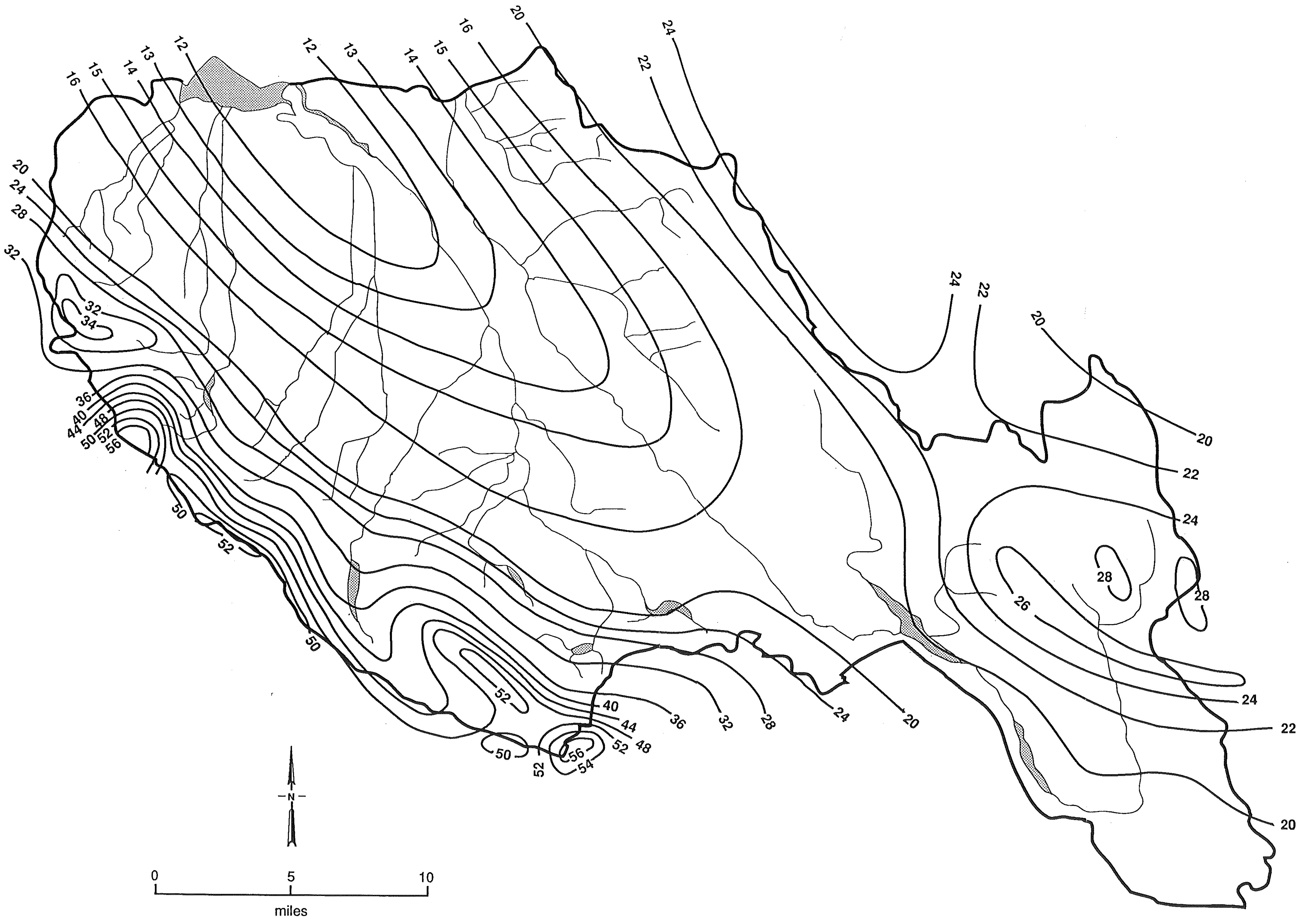
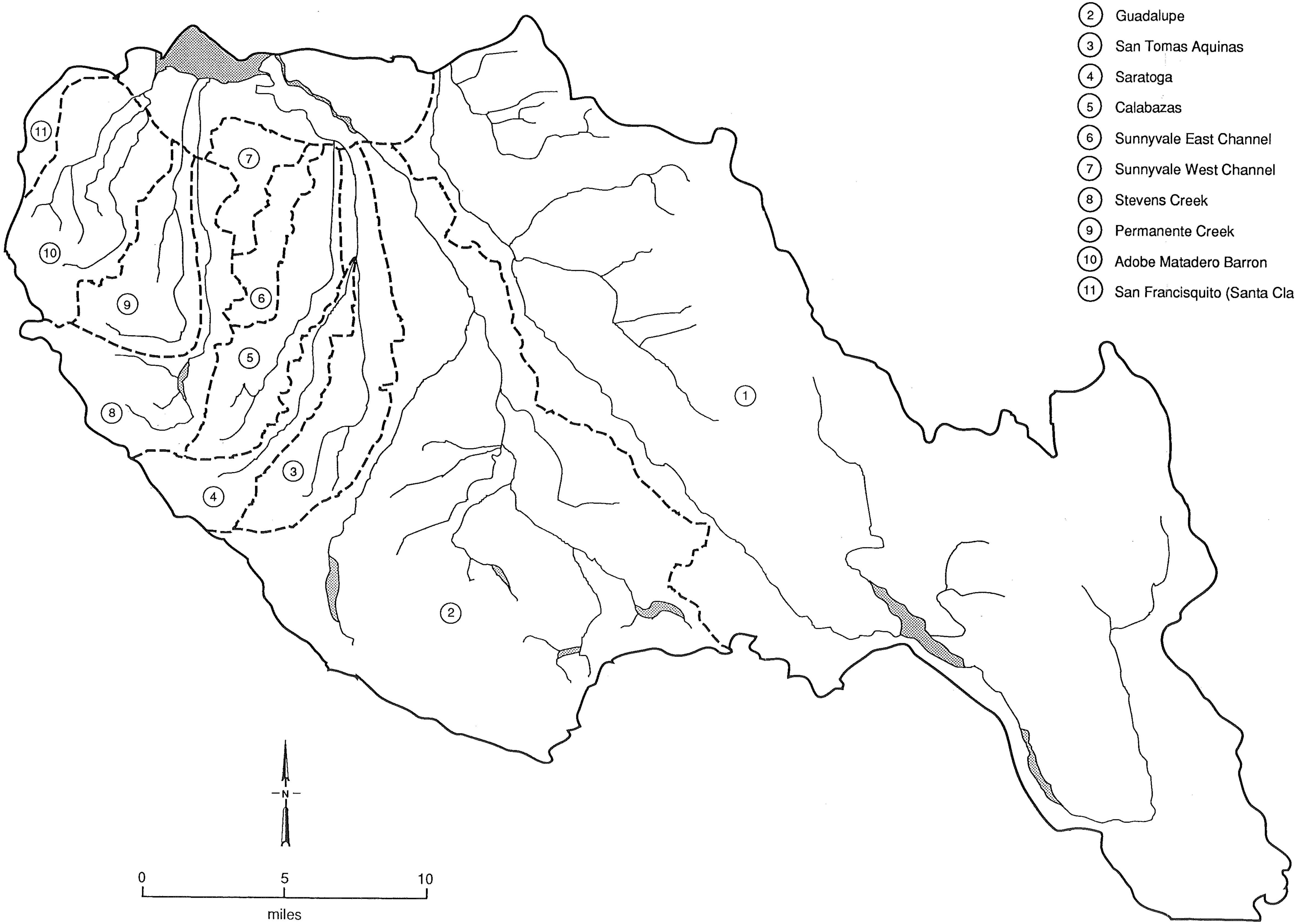


Figure 2-4. MEAN ANNUAL PRECIPITATION IN INCHES



WATERSHED	AREA* (sq miles)	% of TOTAL
① Coyote	124	33
② Guadalupe	108	28
③ San Tomas Aquinas	28	7
④ Saratoga	17	4
⑤ Calabazas	21	6
⑥ Sunnyvale East Channel	7	2
⑦ Sunnyvale West Channel	5	2
⑧ Stevens Creek	12	3
⑨ Permanente Creek	17	4
⑩ Adobe Matadero Barron	34	9
⑪ San Francisquito (Santa Clara County)	7	2
	380	100

* Does not include areas above reservoirs

Figure 2-5. WATERSHEDS IN STUDY AREA

The Guadalupe watershed (approximately 170 square miles in area) consists of the Guadalupe River, Los Gatos Creek, Ross Creek, Guadalupe Creek, and Alamitos Creek. The headwaters of the Guadalupe extend into the Santa Cruz Mountains, where there are a number of headwater reservoirs (Calero, Almaden, Guadalupe, and Lexington) operated by the SCVWD.

Coyote Creek and its tributaries (Berryessa Creek, Upper Penitencia Creek, and Silver-Thompson Creek) drain 352 square miles primarily in the Diablo Range. Approximately 55 percent of the Coyote Creek watershed is above Anderson Reservoir.

To the west of the Guadalupe watershed is a series of nine relatively small watersheds whose streams tend to originate in the Santa Cruz Mountains and then flow through urban areas to the Bay. These streams and their corresponding watershed areas are (from east to west) San Tomas Aquino (27 sq. mi); Saratoga (17 sq. mi); Calabazas (21 sq. mi); Sunnyvale East (7 sq. mi); Sunnyvale West (5 sq. mi); Stevens Creek and Permanente Creek (46 sq. mi); Adobe, Matadero, and Barron creeks (34 sq. mi); and San Francisquito Creek. The San Francisquito Creek watershed area is 41 sq. mi, of which 8 sq. mi are in Santa Clara County (the remainder is in San Mateo County.)

Many of these streams are channelized in the urban areas. In their lower reaches, these streams combine to form several tidal sloughs that flow into the Lower South Bay.

2.5 GEOLOGY

One source of metals in watershed runoff is the erosion of sediment containing naturally occurring minerals. The following discusses the mineralogy of the Study Area to provide a background regarding this source.

The principal bedrock unit in Santa Clara County is the Franciscan Assemblage, which is exposed at the surface at various locations on both sides of Santa Clara Valley. Serpentine, which intrudes the Franciscan Assemblage and is closely associated with it, is the source of most of the metal-bearing mineral deposits in the county.

The Santa Clara Formation, a relatively unconsolidated, nearly soil-like geologic unit made up of clays, silts, sands, and gravels in various proportions, overlays rocks of the Franciscan Assemblage along the margins of the Santa Clara Valley. It was derived from the Franciscan Assemblage rocks through erosional processes, so contains many of the same mineral and/or chemical constituents. The Santa Clara Formation is the source area for the Valley alluvium. The following discusses the mineralogy of the above formations.

Arsenic. Arsenic has been found, associated with mercury, in hydrothermally altered Franciscan sandstone in Lake County (Bailey et al. 1964). Similar deposits may be present in Santa Clara County but these are not known.

Cadmium. Cadmium is not reported to have been found in the source areas of the Santa Clara Valley alluvium. However, as a general statement, cadmium most commonly occurs as a constituent of sphalerite (Morton 1966). Sphalerite, a zinc sulfide, reportedly occurs in the New Almaden Mines and--in trace amounts--in the (abandoned) Hooker Creek mining area.

Chromium. Chromite, an oxide of iron and chromium, has been mined on the eastern slope of the Santa Cruz Mountains and on the western slope of the Diablo Range (Davis and Jennings 1954).

Copper. Copper minerals, including bornite, malachite, azurite, and chalcopyrite, are known to be associated with serpentine deposits and with igneous rocks of the Franciscan Assemblage. The largest known concentration of copper minerals in Santa Clara County is in Hooker Creek, which drains into Lexington Reservoir. However, occurrences of copper minerals have been noted at widely separated localities throughout the central Coastal Ranges (Davis and Jennings 1954), and in the New Almaden Mines (Bailey and Everhart 1964).

Lead. A lead sulfide mineral, galena, occurs in very small amounts with sphalerite, a zinc sulfide that occurs locally in the New Almaden Mines area (Bailey and Everhart 1964).

Mercury. Mercury, both as a native metal and as cinnabar, has been mined extensively in the Guadalupe and New Almaden areas of Santa Clara County. It is associated with silica carbonate rock, which is formed by hydrothermal alteration of shear zones in serpentine. Silica carbonate rock with minor, noncommercial amounts of mercury is relatively common in the western foothills of the Diablo Range as well as in the former mining areas of the eastern part of the Coast Ranges (Bailey et al. 1964).

Nickel. Nickel has been identified as a trace constituent in some serpentines (Bailey et al. 1964). One of the principal mineral associations of nickel in California is pyrhhotite, an iron sulfide mineral that commonly is found in intrusive igneous rocks such as peridotite, associated with other metallic sulfides (Holtz 1966). Pyrhhotite is associated with the copper mineralization in Hooker Creek and elsewhere.

Selenium. Selenium, in the form of a gray mercuric selenide, tiemannite, has been found in the Guadalupe Mines (Bailey and Everhart 1964).

Silver. Silver reportedly occurs with copper minerals and gold adjacent to Hooker Creek and was mined commercially between 1936 and 1939 (Davis and Jennings 1954).

Zinc. Zinc, in the form of a sulfide mineral, sphalerite, reportedly occurs in the New Almaden Mines. It apparently represents a later stage of mineralization than does the mercury (Bailey and Everhart 1964).

2.6 HYDROGEOLOGY

As streams carry eroded materials down from the Santa Cruz Mountains and the Diablo Range, heavier, coarser sediments are deposited first, while lighter, finer materials are carried farther downstream towards the Bay. Thus, the headwater areas consist of more-permeable deposits such as sandstone, mudstone, and conglomerate formations, and the interior of the valley is characterized by less-permeable deposits consisting of gravel, sand, silt, and clay (Sylvester 1986; SERL 1985).

The headwater areas consist predominantly of aquifer materials with discontinuous or leaky aquitards. Here groundwater occurs unconfined or under water table conditions (SERL 1985). The headwater areas are the primary recharge zones and are where the SCVWD operates most of its recharge facilities.

In the Valley floor north of the headwater areas, there is a complex system of discontinuous aquifers consisting of gravel and sand separated by aquitards consisting primarily of clay and silt. An extensive silt-and-clay confining layer separates the water-producing areas into two zones. The upper zone is unconfined near the headwater area and then becomes confined nearer the Bay. The lower zone is confined.

The depth to groundwater varies depending on annual precipitation (and therefore natural recharge), artificial recharge, and extraction by wells. Data collected by the SCVWD in the fall of 1987 indicate that depth to groundwater is relatively shallow (e.g., 10-50 feet) in the headwater area, increasing to depths of 100 to 300 feet in the interior of the basin, and then decreasing to zero as one approaches the Bay. Thus, streams tend to lose water to groundwater, except in the headwater areas where incised streams may intercept perched or locally shallow groundwater.

2.7 WATER SUPPLY

Approximately 50 percent of the water supply provided by the SCVWD is from groundwater; the remainder is provided from imported waters via the State's South Bay Aqueduct, the Hetch Hetchy Aqueduct, and the San Felipe Aqueduct from the Central Valley Project's San Luis Reservoir. To augment natural recharge to groundwater, the SCVWD stores runoff from headwater areas in Coyote, Anderson, Calero, Almaden, Guadalupe, Lexington, and Stevens Creek reservoirs. These headwater areas comprise about 45 percent of the total watershed area. The reservoirs that capture runoff from these areas are estimated to capture approximately 36 percent of the total mean annual runoff from the total watershed. Water is then released, primarily during dry weather, and is either diverted into offline recharge basins or ponded behind in-stream impoundments temporarily constructed for the summer dry-weather period. By segregating high quality upland flows from runoff from the developed areas of the Valley, this reservoir storage and recharge system is effective in controlling nonpoint source pollution and in providing a high quality groundwater drinking water supply. The system is managed such that reservoir releases will not enter the Bay, unless reservoir and recharge capacity are exceeded.

SECTION 3

3.0
PREVIOUS STUDIES

The following is a discussion of the findings of selected stormwater runoff pollution studies that are most pertinent to the Santa Clara Valley NPS Study. The emphasis is on monitoring studies conducted in the Bay Area and in Santa Clara County in particular, although selected national studies are also discussed.

3.1 ASSOCIATION OF BAY AREA GOVERNMENTS 208 STUDY (1976-1977)

As part of the Areawide Waste Management Plan Program (funded under Section 208 of the Water Pollution Control Act Amendment of 1972), the Association of Bay Area Governments (ABAG) conducted various technical studies and developed a Surface Runoff Management Plan. The associated studies included sampling of runoff in the relatively dry 1976-1977 wet season at 22 different stations (55 station-events were sampled) throughout the Bay Area (Litwin et al. 1977). Samples were analyzed for nutrients, solids, bacteria, organics, metals, and floatables. Flow weighted composite sampling was conducted for most constituents. Principal findings were:

- The quality of surface runoff from urban areas was 2 to 3 times more polluted than runoff from open areas.

- The major pollution problems for nonpoint sources were with oil and grease, organics, and heavy metals. Whereas, the total load of nutrients from point source discharges was greater than that from nonpoint sources.

- There appeared to be relatively minor differences in the quality of surface runoff from residential, commercial, and industrial land uses.

- Pollution in storms following a short, dry period (e.g., 2 weeks) was comparable to pollution from storms after much longer dry periods. In other words, pollutants accumulate in an urban area relatively rapidly following a major storm.

3.2 COYOTE CREEK STUDY (1977-1981)

This study, conducted by Woodward-Clyde Consultants (Pitt and Bozeman 1982), investigated the effects of urban runoff on water quality, sediment quality, and biota in Coyote Creek. Extensive biological studies consisted of sampling fish, benthic macroinvertebrates, and insects to assess relative abundance and diversity. The studies were designed to differentiate between the nonurbanized upper reach by the creek and the more urbanized lower reach. Principal conclusions were:

- Dissolved minerals (e.g., as indicated by hardness and total dissolved solids) were higher during dry-weather flow. (These constituents reflect a groundwater source.)

- Lead, zinc, copper, cadmium, and nickel were 2 to 40 times higher in wet weather than in dry weather, in the urban reaches.

- Concentrations of pollutants in water and sediment were typically much higher in the urban reaches than in the nonurban upper reaches.

- There was a significant decrease in the abundance and diversity of biota when passing from the nonurban to the urban reaches. The cause for the decrease in biota could be related to both water quality and physical factors associated with the channelization of the lower reaches of Coyote Creek.

3.3 SAN JOSE STREETSWEEPING EFFECTIVENESS STUDY (1976-1978)

This study was a demonstration project supported by EPA's Storm and Combined Sewer Section. Woodward-Clyde Consultants investigated pollutant accumulation rates on city streets in San Jose, and tested the effectiveness of alternative street sweeping methods to remove pollutants. Conclusions of the study were:

- Significant amounts of heavy metals were found in street dirt and, therefore, street surfaces are a principal source of heavy metals in urban runoff.
- Runoff and erosion from off-street areas is probably responsible for most of the organic and nutrient loads; therefore, street sweeping is not an effective control for these pollutants.
- Street sweeping of smooth asphalt streets would have to be conducted as frequently as once or twice per day to remove 50 percent of the total solids and heavy metals.
- Typical street sweeping frequencies (e.g., once or twice per month) remove less than 5 percent of the total solids and heavy metals in runoff.
- Conventional street sweepers and conventional practices are effective at picking up only relatively large particle sizes. They are, therefore, of little benefit for water pollution control because the amounts of associated pollutants increase significantly as particle size decreases.

- Pollutant accumulation rates were highest when the streets were relatively clean (e.g., following street sweeping or a storm) and tended to decrease with time.

The results of the studies indicate that pollutant accumulation on urban streets occurs relatively rapidly in the days following a storm, and that the accumulation approaches some maximum that is controlled by vehicular turbulence, wind, and other factors. Given this relatively rapid pollutant accumulation process, it is not surprising that street sweeping conducted on a fixed schedule does not appear to be effective.

3.4 USGS/SCVWD WATER QUALITY MONITORING PROGRAM (1979-1981)

The USGS, in cooperation with the Santa Clara Valley Water District conducts an ongoing monitoring program to measure streamflow, water quality, and sediment quality at 12 stations, including 8 stations in the Coyote and Guadalupe watersheds.

During 1979-1981, data were collected and are reported in the USGS Water Resources Investigations Report (Sylvester 1986). These data include 3 dry-weather sampling rounds in 1979-1980 and 3 wet- and 4 dry-weather rounds in 1980-1981. In 1980-1981, automatic samplers were utilized at 4 stations to collect composite samples. Parameters measured in the water included major ions, nutrients, trace metals (dissolved), and biocides. Trace metals were also measured in the sediments.

Conclusions in the report include:

- Specific conductance was inversely related to streamflow and, therefore, reflected dissolution of naturally occurring minerals by interflow which ultimately fed into the streams.

- Turbidity was directly related to streamflow.

- Dissolved oxygen was generally high and appeared to be increased by photosynthesis in reaches where there was abundant algal and aquatic vascular plant growth.

- Concentrations of dissolved arsenic, cadmium, chromium, copper, and lead were generally less than 10 μg/l; mercury was less than 2 μg/l.

- Concentrations of dissolved aluminum, manganese, and zinc were generally less than 100 μg/l. Concentrations of manganese were greater than or equal to 100 μg/l only during dry weather. It was hypothesized that the source of manganese was tertiary mudstones. One source of aluminum was postulated to be feldspar (aluminum silicates) found in graywacke rock, which is the predominant geologic rock unit in the surrounding mountains. High zinc values were attributed to urban sources.

- Concentrations of aluminum, iron, and manganese were greater than the concentration of other trace elements in stream-bottom sediments. This was explained on the basis of geologic sources.

- Concentrations of mercury in the bottom sediments were greater than 1 μg/g only in the Guadalupe watershed. This was attributed to the numerous natural mercury deposits in this basin.

- Concentrations of chromium in bottom sediments were higher at upland stations. This was attributed to chromite deposits located in the headwater areas.

- Organic biocides were usually below detection limits at all stations, although trace levels (<1 μg/l) of chlordane, DDD, DDE, DDT, diazinon, dieldrin, heptachlor, lindane, malathion, 2,4-D, and silvex were detected.

3.5 EPA NATIONWIDE URBAN RUNOFF PROGRAM (1978-1984)

EPA provided approximately $30 million in funding support to 28 different agencies for studies in cities distributed throughout the nation. Important program elements were the monitoring of urban stormwater quality, determining the effects of runoff on receiving water quality, and field testing to determine the performance of control measures.

The resultant data base includes concentrations of 10 or more pollutants in each of more than 2000 runoff events, and detailed performance measurements on a number of different control techniques. Woodward-Clyde Consultants assisted EPA and the 28 regional study teams to design and conduct the field programs, then organized, analyzed, and interpreted resulting data.

An abbreviated listing of some of the pertinent findings of the NURP study (U.S. EPA 1983) includes the following:

- Pollutant levels in urban runoff are highly variable, both for different events at a given site, and also between sites. When the distributional form and the statistical parameters were determined, the variable results were found to be amenable to useful characterization, consolidation, and comparison. Results of these evaluations are presented in the project report, and are useful as reference material and for comparisons to aid in the evaluation of monitoring results at other study sites.

- Event mean concentrations for all pollutants at each of the individual study sites were found to vary in accordance with a lognormal probability distribution, and exhibited comparable variances. This allowed the variable individual results for the different sites to be compared, using a single value representing the site median concentration.

- Site median concentrations were also found to be variable, and differences were found to be best described by a lognormal distribution. Concentration differences could not be attributed to urban land uses monitored [commercial and residential]. Differences in mass loads discharged from different land use types were dominated by the fraction of impervious surface typical of the use category, which determines the quantity of the rainfall that runs off. On a broader scale, the regional effect of annual rainfall quantities was found to have a major influence on mass loading rates.

- Among the control measures examined, three were studied in sufficient depth to permit general conclusions on performance capabilities. Detention basins that maintain a permanent pool (wet ponds) or which incorporate outlet structures that retard draining for 24 to 48 hours were found to be effective control measures for removing pollutants from storm runoff. Infiltration devices that reduce the quantity of surface runoff by enhancing percolation through the soil into groundwater were also found to be an effective control approach to areas where appropriate site conditions are present. Street sweeping was found to be generally ineffective as a water quality control measure. Poor performance was attributed to low efficiency in picking up the smaller particles (which contain the bulk of the pollutants of concern), and in the imbalance between storm frequency and practical sweeping schedules.

- A priority pollutant sampling program was conducted in which a total of 121 urban runoff samples were collected at 61 sites (two storm events per site) at 20 of the NURP projects. Seventy-seven priority pollutants were detected, including 14 inorganic and 63 organic pollutants. The inorganic pollutants most often detected (greater than 90 percent of the samples) were copper, lead, and zinc. Other frequently detected inorganics were arsenic (52 percent), chromium (58 percent), cadmium (48 percent), nickel (43 percent), and cyanide (23 percent). Selenium was detected in 11 percent of the samples. A comparison with EPA water quality criteria and drinking water standards revealed numerous exceedances of the prescribed levels.

- Organic pollutants measured as part of the priority pollutant sampling program were detected much less frequently and at lower concentrations than the inorganic pollutants. The following are constituents detected in at least 10 percent of the samples: pesticides (α-hexachlorocyclohexane - 20 percent, Lindane - 15 percent, Chlordane - 17 percent, α-Endosulfa - 19 percent); halogenated aliphatics (dichloromethane - 11 percent); phenols (phenol -14 percent, pentachlorophenol - 19 percent, 4-nitrophenol - 10 percent); bis(2-ethylhexyl)phthalate - 22 percent; and polycyclic aromatic hydrocarbons (chrysene - 10 percent, fluoranthene - 16 percent, phenanthrene - 12 percent, and pyrene - 15 percent).

3.6 AQUATIC HABITAT INSTITUTE TOXIC CONTAMINANT LOADING ASSESSMENT (1987)

The Aquatic Habitat Institute conducted an assessment of loads of toxic contaminants entering the San Francisco Bay Delta from a variety of sources, including urban runoff. The AHI report (Gunther et al. 1987) recognized that the local urban runoff water quality data were inadequate for estimating loads, and utilized other sources (primarily the results of the above-described Nationwide Urban Runoff Program Priority Pollutant Monitoring Project). Loads were projected using a runoff coefficient model and NOAA land use data. Uncertainty in the input conditions were examined with a sensitivity analysis. Results indicated that urban runoff was comparable to other sources for most trace metals and was higher than other sources for total hydrocarbons. Estimates could not be made for polycyclic aromatic hydrocarbons because of the lack of consistency of measurements above detection levels.

3.7 ASSOCIATION OF BAY AREA GOVERNMENTS' HYDROCARBON RUNOFF STUDY (1988)

Fam et al. (1988) examined the hydrocarbons contained in urban runoff from 15 watersheds in the San Francisco Bay Area over a 2-year period. The analytical method utilized liquid and gas chromatography to separate extracted organics into aliphatic, aromatic, polar, and nonelutable fractions. Used motor oil, fresh and weathered diesel fuel, and plant waxes were also similarly analyzed. Findings from the study included:

- Catchments with higher percents of commercial land use yielded runoff with a higher ratio of aliphatic to aromatic hydrocarbons. Aliphatic hydrocarbons are generally considered to be biodegradable and only become toxic at elevated concentrations. Polynuclear aromatics, however, are more toxic than aliphatic hydrocarbons and tend to accumulate in food chains. In this study the most commonly identified PNA hydrocarbons were anthracene, fluoranthene, indenol pyrene, and benzo-perylene.

- Temescal Creek (Alameda County) chromatograms were often comprised of primarily (90 percent) diesel fuel, which was attributed to a nearby bus repair yard.

- The Elmhurst Creek station, which collected runoff from a heavily industrial area, consistently exhibited chromatographic patterns identical with the aliphatic fraction of used motor oil.

3.8 SYNTHESIS

The studies described above indicate that wet-weather runoff from urban areas, although highly variable, tends to have elevated concentrations of heavy metals (especially copper, lead, and zinc), when compared to dry-weather streamflow or wet-weather runoff from undeveloped areas. Organics are much less frequently detected and have far lower concentrations than the heavy metals.

The interaction between variable hydrologic factors within an urbanized watershed causes runoff quality to be quite variable and difficult to characterize in terms of causative factors (e.g., runoff volume, land use).

Trace metals and organic constituents tend to be adsorbed to fine particulate matter. Consequently, elevated levels of certain constituents (e.g., aluminum, manganese, mercury, chromium) may be related to erosion of natural deposits of these metals in steeper, less-stable, upland portions of the watersheds.

Because of the attraction of trace metals and organics to fine particulate matter, stream bottom sediments often prove to be a good indicator of the presence of organics. In Santa Clara County, such analyses have indicated the presence of biocides and hydrocarbons, in addition to trace metals.

Hydrocarbon studies in the Bay Area show that runoff commonly contains aliphatic hydrocarbons which are believed to derive from used motor oils and diesel fuels. The prevalence of polynuclear aromatics is less well documented, but of more concern because of its toxicity.

Pollutants tend to accumulate on urban streets following a storm (or street sweeping) such that a quasi-equilibrium level is reached in a few weeks. This relatively rapid accumulation process, coupled with the tendency of pollutants to be associated with the finer particle size fractions (which are difficult to pick up with conventional street sweeping equipment and practices), limits the utility of street sweeping as an overall effective control measures. However, sweeping more strategically (e.g., for large parking lots which may yield elevated hydrocarbons) may be appropriate in many locations.

SECTION 4

SECTION 4.0
FIELD MONITORING PROGRAM

This section summarizes the scope of the Field Program. A detailed description of the Program, including scope and methods, is provided in Appendix A. The Field Program also included a toxicity testing element, described in Section 7.0.

4.1 INTRODUCTION

The field monitoring program was designed to provide data to characterize runoff concentrations and to estimate nonpoint source pollutant loads entering the Lower South Bay from Santa Clara County. Monitoring during storm events was conducted to provide data to calibrate and verify the wet-weather loading model. Hydrological and water quality data associated with base dry-weather streamflows were also collected to estimate dry-weather loads. A secondary objective was to evaluate the toxicity of both storm-related and dry-weather flows in streams entering the Bay (Section 7.0).

The field monitoring program utilized three types of stations, as follows:

- Land use stations - Small, relatively homogenous land use catchments were selected to represent major land use categories. Water quality data from these catchments were used as input to the loading model.

- Stream stations - Stations that were located in the lower portions of watersheds and which received a composite of storm runoff waters from multiple land use categories. Stream stations were monitored to provide data to calibrate the loading model.

- Reservoir stations - These stations were utilized to provide data to establish upstream background water quality conditions and to estimate loads associated with reservoir releases.

The field program can be conveniently described in terms of several elements, as follows:

- The hydrology monitoring element consisted of continuously monitoring flows at stream and land use stations at hourly intervals throughout the duration of the monitoring program in order to estimate the hydrological component of the load.

- Water quality monitoring was conducted in three program elements: wet weather, dry weather, and reservoir release. Wet-weather water quality monitoring consisted of monitoring water quality at land use and stream stations for seven storm events. Flow composite samples were collected using automatic samplers. The purpose of this sampling was to provide a basis for estimating pollutant loads during winter storm events. In order to estimate loads during winter base flow periods and summer dry-weather periods, dry-weather water quality monitoring was conducted by obtaining grab samples at the stream stations eight times through the program. To provide information on upland water quality, one round of reservoir release water quality monitoring was conducted at seven stations immediately downstream of reservoirs.

- Bottom sediment sampling was conducted at the four stream stations. This sampling was conducted quarterly throughout the first year of the study. The purpose of this monitoring was to evaluate the role of bottom sediments as both a source and sink of pollutants associated with nonpoint source runoff.

- The bioassay testing program was designed as an initial screening of toxicity exerted by wet-weather samples obtained from land use and stream stations and dry-weather samples at stream stations.

In addition to the above, a number of special studies were conducted to address specific concerns. These studies examined: (1) dissolved oxygen concentrations during storm events at selected stream stations, (2) dissolved metal concentrations in runoff, (3) settling rates of suspended particulates in stormwater collected from stream stations, and (4) concentrations of fecal streptococci bacteria in stormwaters.

4.2 SAMPLING STATIONS

Sampling stations were located as shown in Figure 4-1 and were selected based on catchment characteristics, hydraulic factors, and accessibility and safety. The following describes the catchment and station characteristics for land use and stream stations. For reference, Table 4-1 summarizes general information for each station.

4.2.1 Land Use Catchments

The land use catchments were selected to represent the following major land use categories: light and heavy industry, commercial, single- and multi-family residential, and open.

Station L1 was a light industrial site located on Junction Avenue. The catchment drains a 22-acre industrial park bordered by Charcot Avenue, Dado Avenue, and Coyote Creek (in San Jose). The station was located in a manhole on Junction Avenue near the Southern Pacific Railroad (SPRR) lines.

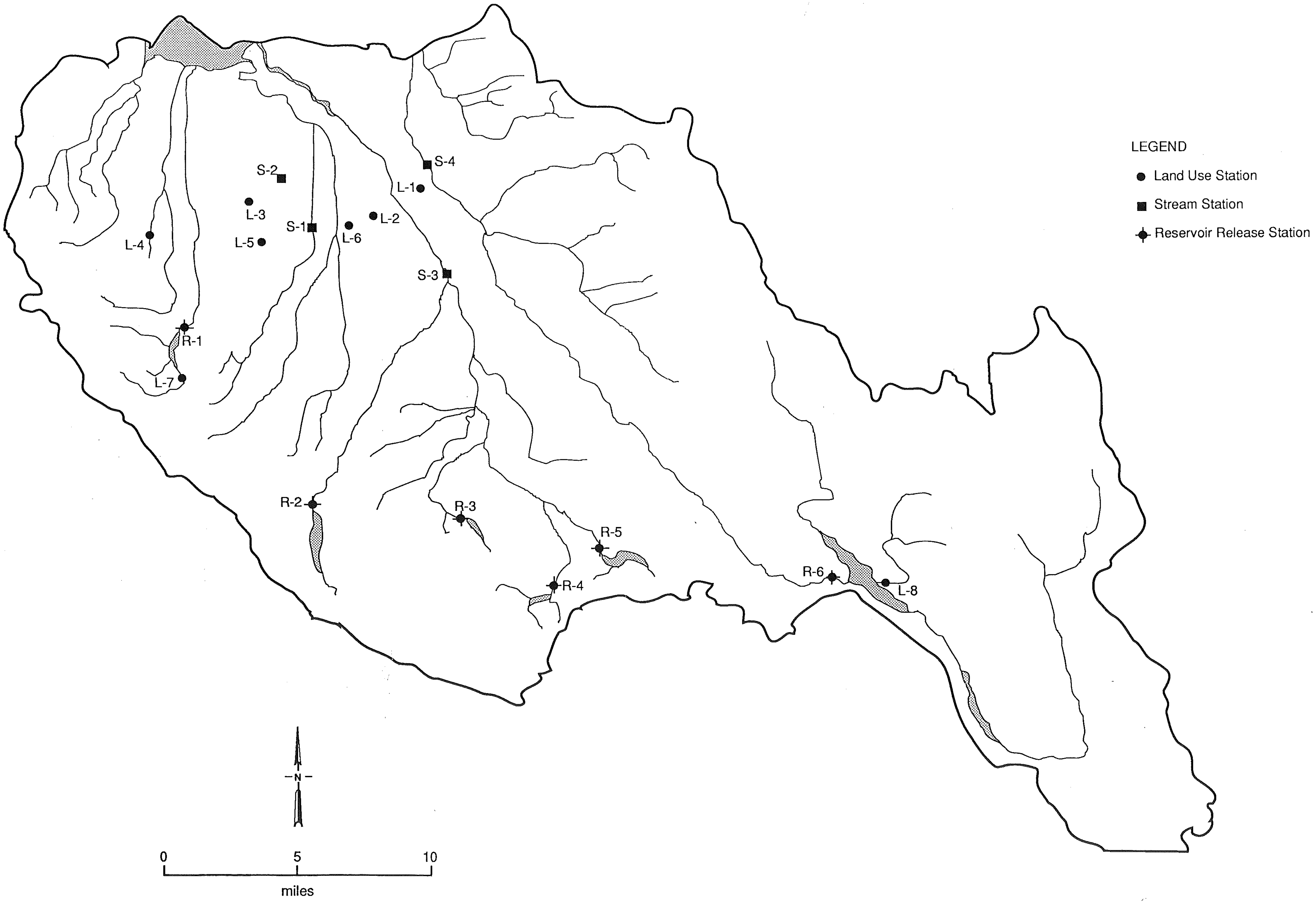


Figure 4-1. SAMPLING STATION LOCATIONS

Table 4-1. STATION DESCRIPTION

Designation	Type of Station	Location	Location	Jurisdiction	Principal Land Use	Drainage Area (acres)	Conveyance	Remarks
L1	Land Use	Junction Avenue, between Charcot and Dado Streets	San Jose	San Jose	industrial park	22	30" R.C.P.	Manhole station, with weir installed
L2	Land Use	Walsh Avenue, near SPRR	Santa Clara	Santa Clara	heavy industry	28	27" R.C.P.	Manhole station, with weir installed
L3	Land Use	Frances and Beamer streets, north of Sunnyvale Caltrans RR Station	Sunnyvale	Sunnyvale	commercial	265	42" R.C.P.	Manhole station, with weir installed
L4	Land Use	Hale Creek, near Magdalena Rd.	Santa Clara County	SCVWD	low-density single-family residential (hillside)	1,633	open channel	SCVWD gaging station No. 33
L5	Land Use	Sunnyvale East Channel, near Fremont Avenue	Sunnyvale	SCVWD	single-family residential (valley)	2,080	channelized	Highly-erodable channel, rating developed
L6	Land Use	Pasetta and Williams, near San Tomas Expressway and SPRR	Santa Clara	Santa Clara	multi-family residential	85	33" R.C.P.	Manhole station, with weir installed

Table 4-1. STATION DESCRIPTION (continued)

Designation	Type of Station	Location	Location	Jurisdiction	Principal Land Use	Drainage Area (acres)	Conveyance	Remarks
L7	Land Use	Stevens Creek, above Stevens Creek Reservoir	Santa Clara County	SCVWD	open (forest)	8,410	natural	Rating developed but not considered reliable because of backwater effects
L8	Land Use	Packwood Creek, at Jackson Ranch (east of Anderson Reservoir)	Santa Clara County	SCVWD	open (ranchland)	6,464	natural	SCVWD gaging station No. 57
S1	Stream	Calabazas Creek, at Wilcox School	Santa Clara	SCVWD	mixed	9,216	natural	SCVWD gaging station No. 26A
S2	Stream	Sunnyvale East Channel, at Bayshore Frontage Road (A.P. Sta 2)	Sunnyvale	SCVWD	mixed	3,437	channelized	SCVWD gaging station No. 74
S3	Stream	Guadalupe River, at San Jose	San Jose	SCVWD	mixed	15,904	natural	USGS gaging station No. 169000
S4	Stream	Coyote Creek, at Montague	San Jose	SCVWD	mixed	79,552	natural	SCVWD high-flow gaging station No. 2060
R1	Reservoir Release	Below Stevens Creek Reservoir (A.P. Sta 14)	Santa Clara County	SCVWD	open	10,924	natural	SCVWD gaging station No. 44

Table 4-1. STATION DESCRIPTION (concluded)

Designation	Type of Station	Location	Location	Jurisdiction	Principal Land Use	Drainage Area (acres)	Conveyance	Remarks
R2	Reservoir Release	Below Lexington Reservoir	Santa Clara County	SCVWD	open	23,859	natural	SCVWD gaging station No. 67
R3	Reservoir Release	Below Guadalupe Reservoir	Santa Clara County	SCVWD	open	3,808	natural	SCVWD gaging station No. 17
R4	Reservoir Release	Below Almaden Reservoir	Santa Clara County	SCVWD	open	7,667	natural	SCVWD gaging station No. 16
R5	Reservoir Release	Below Calero Reservoir	Santa Clara County	SCVWD	open	4,621	natural	SCVWD gaging station No. 13
R6	Reservoir Release	Below Anderson Reservoir	Santa Clara County	SCVWD	open	124,787	natural	SCVWD gaging station No. 9

Station L2 was a heavy-industrial site that drains Walsh Avenue between the SPRR lines and Lafayette Street. This 28-acre catchment included warehouse distribution centers involving heavy truck traffic, a used-car parts distributor, a commercial carpet cleaning service, a printing shop, and small miscellaneous manufacturing and office facilities.

Station L3 was a manhole station located at the intersection of Frances and Beamer streets, north of the Sunnyvale Caltrans Station. The 300-acre catchment represented commercial and single-family residential land use and included the Sunnyvale Town Center and the Caltrans Station.

Station L4 was located on Hale Creek near Magdalena Road. It drains a 1633-acre, low-density (1-2 dwelling units/acre), single-family residential area in Los Altos Hills. The station corresponded to SCVWD gaging station No. 33.

Land use Station L5 was located on Sunnyvale East Channel at Fremont Avenue. It drains a 2080-acre predominantly single-family residential area. The monitoring station was just upstream of a concrete apron and box culvert which passes under Fremont Avenue.

Station L6 was a 85-acre catchment consisting of a multi-family residential area bounded by Passetta, Williams, and Monroe streets, and Deborah Drive, and a single-family residential area located along Sheraton Drive and El Capitan Avenue.

Station L7 was on Stevens Creek, just upstream of Camp Castanoan Bridge, above Stevens Creek Reservoir. The 8410-acre drainage area consisted primarily of steep, heavily forested land in the Santa Cruz Mountains.

Station L8 was a second open land use catchment (6464 acres in area) located in the Diablo Range and draining primarily open ranchland. The station corresponded to the SCVWD gaging station No. 57 on Packwood Creek, upstream of Anderson Reservoir.

4.2.2 Stream Stations

The following four stream stations were selected at locations near the Bay, but above the zone of tidal influence.

Station S1 was located at the SCVWD gaging station No. 26A, located on Calabazas Creek near Wilcox school. The drainage area is 14 square miles and consists of approximately 80 percent residential/commercial and 20 percent open.

Station S2 was located on Sunnyvale East Channel, just upstream of Awhanee Avenue (a frontage road along Bayshore Freeway). This catchment has an area of 5.2 square miles and is wholly urbanized, consisting of residential (68 percent) and commercial (32 percent) land use on the valley floor. The station corresponds to the SCVWD gaging station No. 74.

These two stations were selected to be representative of the smaller more urbanized watersheds on the west side of the Study Area.

Station S3 corresponded to the USGS station No. 1119000 on the Guadalupe River, located downstream of the confluence with Los Gatos Creek. This station has a total drainage area of 146 square miles (20 percent of the Study Area) and includes Los Gatos Creek and Lexington Reservoir, Guadalupe Creek and Guadalupe Reservoir, Ross Creek, Alamitos Creek and Almaden Reservoir, and Calero Creek and Calero Reservoir. This station was selected because it drains a large urbanized area that is accurately gaged. The area of the catchment below the reservoirs is approximately 85 square miles. The land use in this area is 30 percent open, 61 percent residential, 5 percent commercial, and 4 percent industrial.

Station S4 was located on Coyote Creek at Montague Expressway at the SCVWD high-flow gaging station No. 2060. This catchment includes Upper Penitencia and Silver and Thompson creeks, and Anderson and Coyote reservoirs. The catchment area below Anderson Reservoir is approximately 120 square miles, 64 percent of which is open ranch land located in the foothills of the Diablo Range. The remaining land use consists of 30 percent residential, 1 percent commercial, and 5 percent industrial. The SCVWD gaging station at this location was designed to record only flood stages, so this station had to be rated for more typical lower storm-event flows.

4.2.3 Reservoir Stations

The reservoir stations were located at SCVWD gaging stations below Stevens Creek, Lexington, Guadalupe, Almaden, Calero, and Anderson reservoirs (Table 4-1).

4.3 SAMPLING AND ANALYSIS PROGRAM

The field study was designed to accurately quantify discharges throughout the year and to enable flow-weighted compositing of storm runoff samples. Thus, monitoring of stage (water depth) was performed continuously throughout the year, at all stations that had year-round flow. Stage was converted to flow with rating curves that were either previously established or developed as part of this study.

Water quality constituents selected for sampling and analysis were selected based on water quality concerns and issues in the Lower South Bay (Section 6.1) and existing national and local NPS data (Section 3.0). The overall approach of the water quality studies was to examine a wide range (or "full suite") of potential pollutants in the early phases of the study and then develop a more refined list (or "reduced suite") of pollutants based upon results of the initial surveys (Table 4-2).

Table 4-2. SUITES FOR CHEMICAL ANALYSIS OF WATER QUALITY SAMPLES

Class	Complete Suite	Reduced Suite
Organics	Total Organic Halogens	Total Organic Halogens
	TOC	TOC
	Volatiles (624-GC/MS)	
	Semi-volatiles (625-GC/MS)	PNA (610)
(608)	Organochlorine pesticides (608)	Organochlorine pesticides (608)
	Chlorinated herbicides (8150)	
Metals, Total	Arsenic	Arsenic
	Cadmium	Cadmium
	Chromium (total)	Chromium (total)
		Chromium (hexavalent)
	Copper	Copper
	Lead	Lead
	Mercury	Mercury
	Nickel	Nickel
	Selenium	Selenium
	Silver	Silver
	Zinc	Zinc
Nutrients	TKN	TKN
	NH_3-N	
	NO_2 and NO_3	
	Total Phosphate	
Bacteria	Total and fecal coliform	Total and fecal coliform
Other	BOD_5	BOD_5
	Temperature	Temperature
	pH	pH
	TSS	TSS
		Total hardness
		Turbidity

The overall approach and list of sediment quality constituents (Table 4-3) were similar to those described for the water quality testing program.

4.4 SCHEDULE

The field monitoring program was initiated in February 1988 and completed in April 1989. Figure 4-2 shows the schedule for each of the program elements previously described in Section 4.1.

Table 4-3. SUITES FOR CHEMICAL ANALYSIS OF SEDIMENT QUALITY SAMPLES

Class	Complete Suite	Reduced Suite
Organics	TOC	
	Volatiles (8240-GC/MS)	
	Semi-volatiles	PNA (8310) (8270-GC/MS)
	Organochlorine pesticides (8080)	Organochlorine pesticides (8080)
	Chlorinated herbicides (8150)	
Metals, Total	Arsenic	Arsenic
	Cadmium	Cadmium
	Chromium (total)	Chromium (total)
		Chromium (hexavalent)
	Copper	Copper
	Lead	Lead
	Mercury	Mercury
	Nickel	Nickel
	Selenium	Selenium
	Silver	Silver
	Zinc	Zinc
Nutrients	TKN	
	NH_3-N	
Other		Sediment particle size

PROGRAM ELEMENT	1988												1989						
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
1. Reservoir Water Quality		(1) FS ●																	
2. Dry-Weather Water Quality		(1) FS ●	(2) ●		(3) ●			(4) ●				(5) ●		(6) ●		(7) ●			
3. Wet-Weather Water Quality				(1) FS ●							(2) FS ●		(3) ●	(4,5) ● ●	(6,7) ● ●				
4. Wet-Weather Toxicity														(1) ●	(2,3) ● ●				
5. Dry-Weather Toxicity												(1) ●		(2) ●		(3) ●			
6. Sediment Sampling			(1) FS ●		(2) ●			(3) ●				(4) ●							
7. Dissolved Oxygen														(1) ●					
8. Dissolved Metals															(1,2) ● ●				
9. Settling Column Tests															(1) ●				
10. Fecal Streptococci													(1) ●						

LEGEND

FS - Full Suite of Chemical Analysis. Reduced Suite was Performed on other Sampling Events.

Note: Numbers in ( ) denote number of the sampling event or test.

Figure 4-2. SAMPLING SCHEDULE

SECTION 5

5.0
HYDROLOGY

There is a great deal of historical hydrologic data available for the Santa Clara Valley, and an extensive rainfall and streamflow monitoring network has been operating for several decades. The Santa Clara Valley Water District (SCVWD), the U.S. Geological Survey, the National Weather Service, and other agencies have collected rainfall and streamflow data for use in water supply and water quality studies. The following sections summarize these historical data, both to provide insight into the hydrologic processes operating in the valley (and therefore to guide the hydrologic modeling effort) and to address the representativeness of the storms monitored in this study. In addition, the hydrologic data collected as part of this study for 1988-89 are presented. Section 5.1 discusses precipitation data; Section 5.2 discusses streamflow data and rainfall-runoff relationships. Section 5.3 summarizes the rainfall-runoff modeling performed for this study using the Stormwater Management Model (SWMM). A detailed description of SWMM modeling is provided in Appendix B.

5.1 PRECIPITATION

This section provides some background on the available precipitation data in the Santa Clara Valley. Section 5.1.1 describes the existing precipitation monitoring network, including the types of rain gages used, the spatial distribution of gages, and the periods of record available. This is followed in Section 5.1.2 by an analysis of the historical precipitation data, including analyses of spatial and temporal trends and a statistical description of storm events. Section 5.1.3 discusses the storm events sampled in this study and addresses how representative they are of the historical record.

5.1.1 Precipitation Monitoring Network

Over 60 rainfall gages have been in operation in the Santa Clara Valley over the past two decades. Of these, 30 are continuous recording gages that record at 15-minute or 1-hour intervals, while the remainder are gages that record daily rainfall totals. The National Weather Service currently operates one hourly recording gage near the San Jose airport. All other rainfall gages are operated as part of the Santa Clara Valley Water District's monitoring network (SCVWD 1982a).

Continuous-recording rainfall records are necessary for detailed analyses of rainfall patterns, event statistics, and rainfall-runoff relationships. Consequently, this discussion will focus on the 30 or so recording gages in the Santa Clara Valley. Figure 5-1 shows the locations of recording gages in the Santa Clara Valley. Because the monitoring network was designed to aid the SCVWD in operating its reservoir and water supply system, the recording gages are not evenly distributed and tend to be concentrated near the reservoirs in the Santa Cruz Mountains and the Diablo Range. Twelve recording gages are located in the Santa Cruz Mountains and foothills, nine are in the eastern Diablo Range, and nine are on the valley floor. The overall network density for recording gages is approximately 25 square miles per gage. Gage elevations range from 7 feet mean sea level (MSL) near San Francisco Bay to 3800 feet (MSL) in the Santa Cruz Mountains.

Three types of recording gages are operated in the valley. The majority of gages are 15-minute weighing gages operated by the SCVWD. These gages record whenever at least 0.1 inch of rainfall occurs in a 15-minute period, and have a precision of one-tenth of an inch. During the 1983-84 season, the SCVWD also installed a number of radio-telemetry gages in parallel with several of their 15-minute weighing gages. These radio gages are tipping-bucket gages which update cumulative rainfall totals whenever the 0.04-inch (1-mm) tipping buckets fill (i.e., at constant

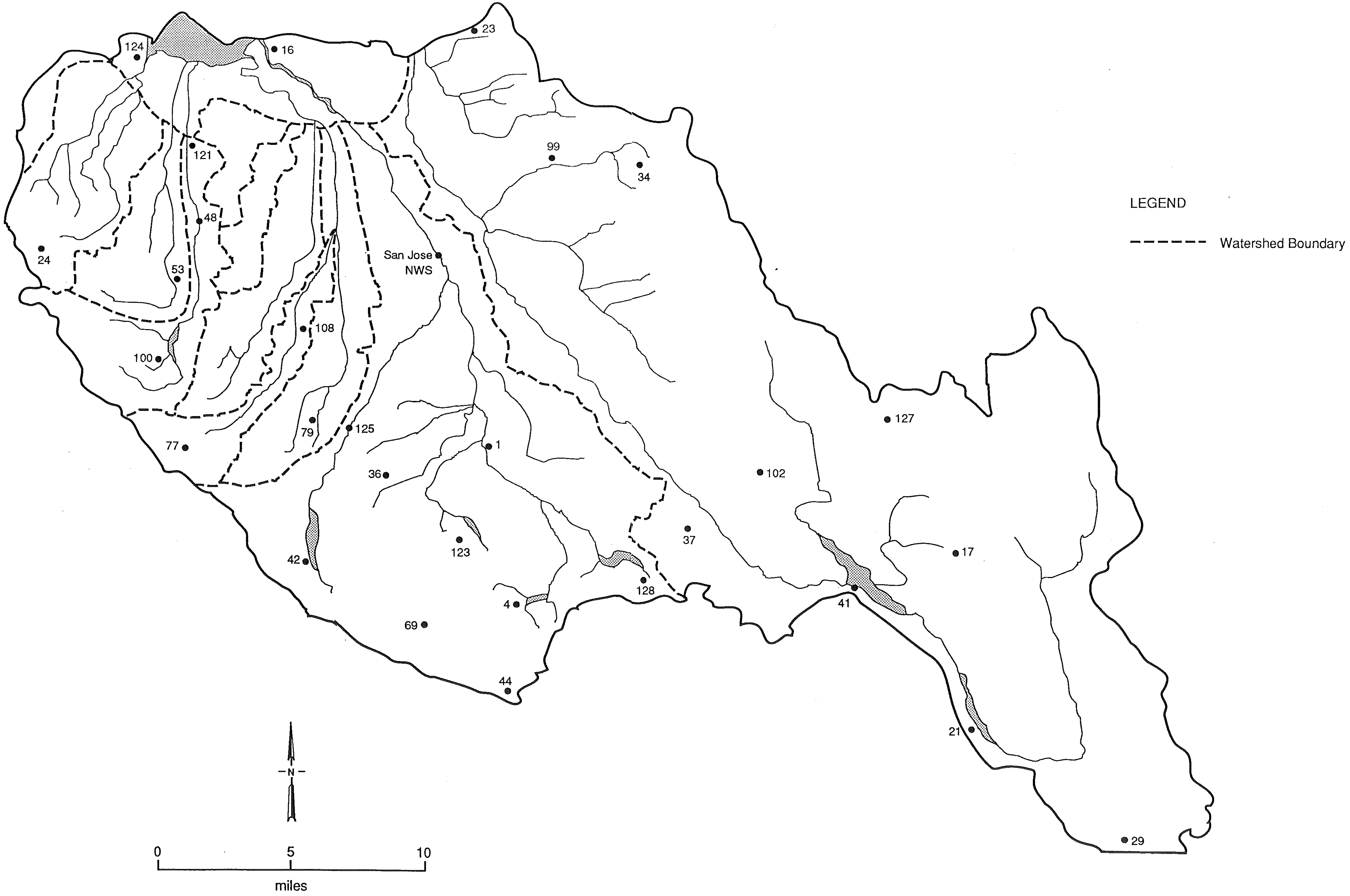


Figure 5-1. LOCATION OF RECORDING PRECIPITATION GAGES

volume increments, varying time intervals). The third type of recording gage is the National Weather Service gage in San Jose. This gage is a weighing gage which records rainfall at hourly intervals to a precision of one-hundredth of an inch.

Figure 5-2 is a chart showing the periods of record for the various recording rain gages. Prior to 1965, many of these gages were nonrecording daily gages, and most of the SCVWD recording gages were installed between 1965 and 1975. Prior to 1974, there are many discontinuities in the SCVWD 15-minute records, and the most complete and reliable 15-minute records are for the post-1974 period. The longest available record is for the San Jose National Weather Service gage, with an hourly record dating back to 1948 and a daily record dating back to 1874.

The precipitation monitoring network in the Santa Clara Valley is extensive, with approximately one recording rain gage per 25 square miles. The recording rain gages are supplemented by numerous non-recording daily rain gages that provide important information on the spatial variability of rainfall. While there are no definitive rules on how many rain gages are sufficient for hydrologic modeling, the existing network in the Valley has a higher density of rain gages than do any of the surrounding Bay Area counties. The density of the network also far exceeds the following minimum densities recommended by Linsley et al. (1982):

- One gage per 230 - 250 square miles in flat terrain, temperate climates.
- One gage per 40 to 100 square miles in mountainous terrain

Since half of the recording gages were not operating prior to 1974, the density of the network prior to 1974 drops to about one gage per 50 square miles. In addition, several key gages representing the western portion of the Valley floor (gages 48, 121, and 129) were not installed until 1974.

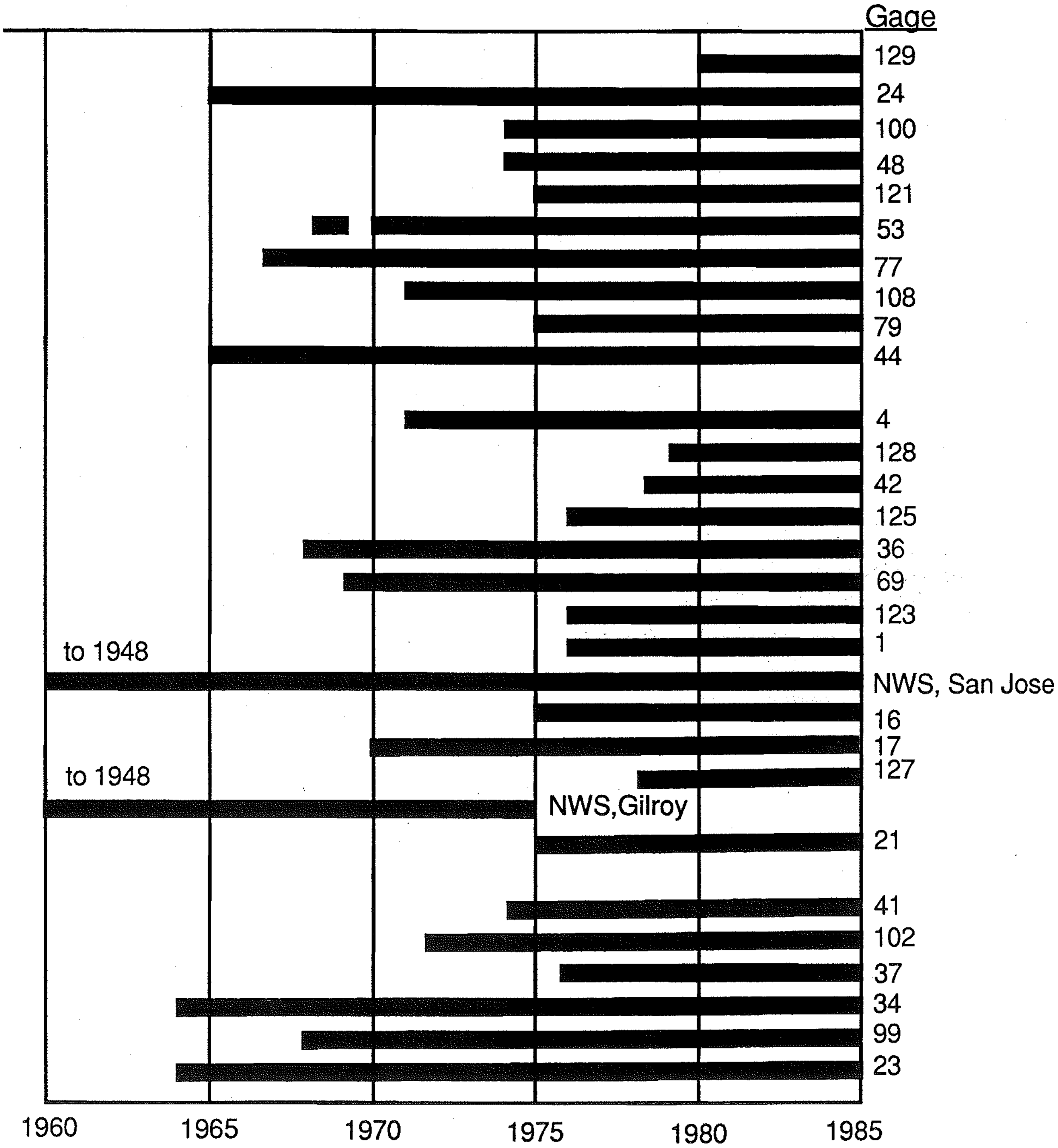


Figure 5-2. Periods of Record for Santa Clara Valley Recording Rainfall Gages

Because these gages are critical in describing rainfall in the western catchments (Adobe Creek, Barron Creek, Matadero Creek, Permanente Creek, Stevens Creek, Sunnyvale East Channel, Sunnyvale West Channel, and Calabazas Creek), runoff modeling and loads estimation for this study focused on the post 1974 period.

5.1.2 Analysis of Historical Precipitation Records

The following is an analysis of historical precipitation records to provide insight into (1) the spatial distribution of rainfall, (2) seasonal and annual variability of rainfall volumes, and (3) storm event statistics.

5.1.2.1 Spatial and Orographic Distribution of Rainfall. Rainfall in the Santa Clara Valley varies spatially due to the path that storms take from west to east and due to the orographic effects of the Santa Cruz Mountains and the Diablo Range. Storms originate in the Pacific Ocean, and usually cross over the Santa Cruz Mountains before arriving in the valley.

Orographic effects on precipitation are strong in the region. As storms move across the Santa Cruz Mountains, air masses rise over the mountains and are cooled, decreasing the saturation vapor pressure of the air (thus bringing the air closer to saturation). The highest rainfall occurs at high elevations in the Santa Cruz Mountains, where mean annual rainfall ranges up to 50 inches. Once the storms cross the mountains and descend into the valley, the air masses are warmed and become less saturated. Rainfall totals are, therefore, considerably lower on the valley floor, where mean annual totals range from 10 to 15 inches. As storms rise again over the Diablo Range, annual rainfall totals increase to a range of 16 to 30 inches.

Figures 5-3a and 5-3b are plots of mean annual precipitation versus elevation for recording gages in the Santa Cruz Mountains and Diablo Range, respectively. The effect of elevation on mean annual precipitation is strongest in the Santa Cruz Mountains, where mean annual precipitation may

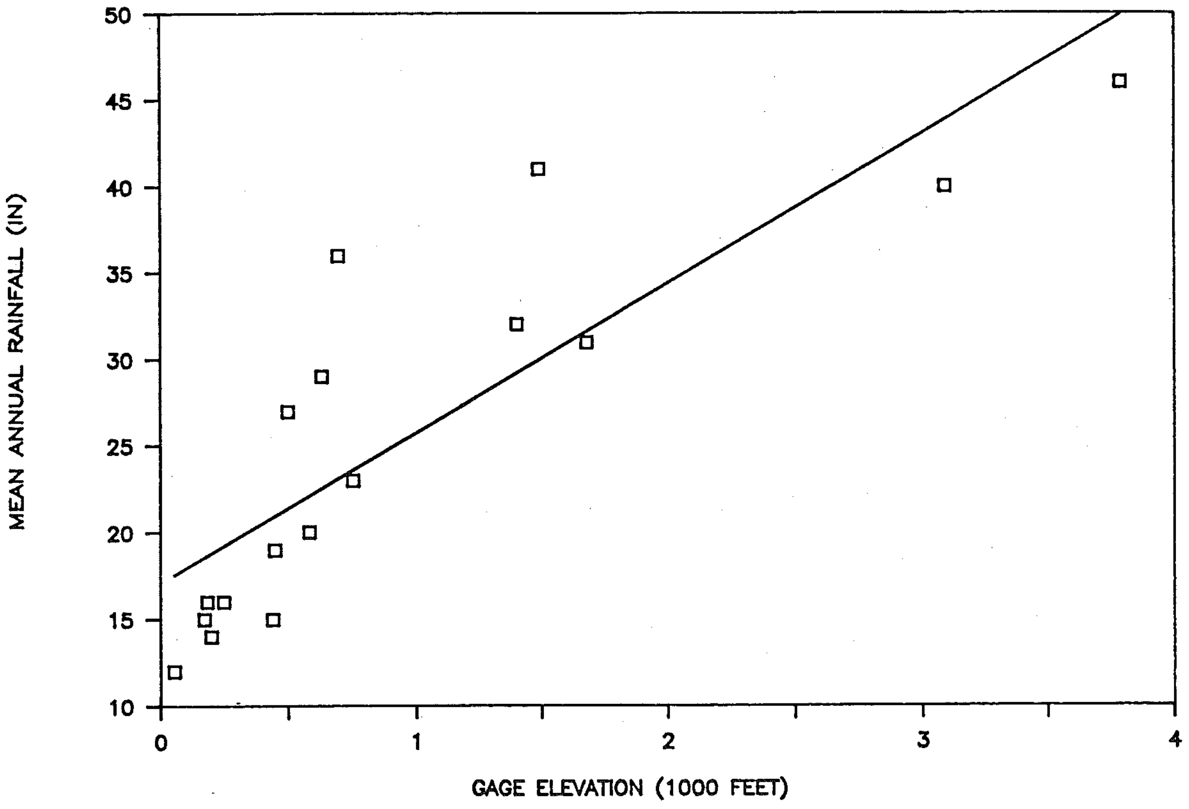


Figure 5-3a. MEAN ANNUAL RAINFALL VS. ELEVATION, SANTA CRUZ MOUNTAINS

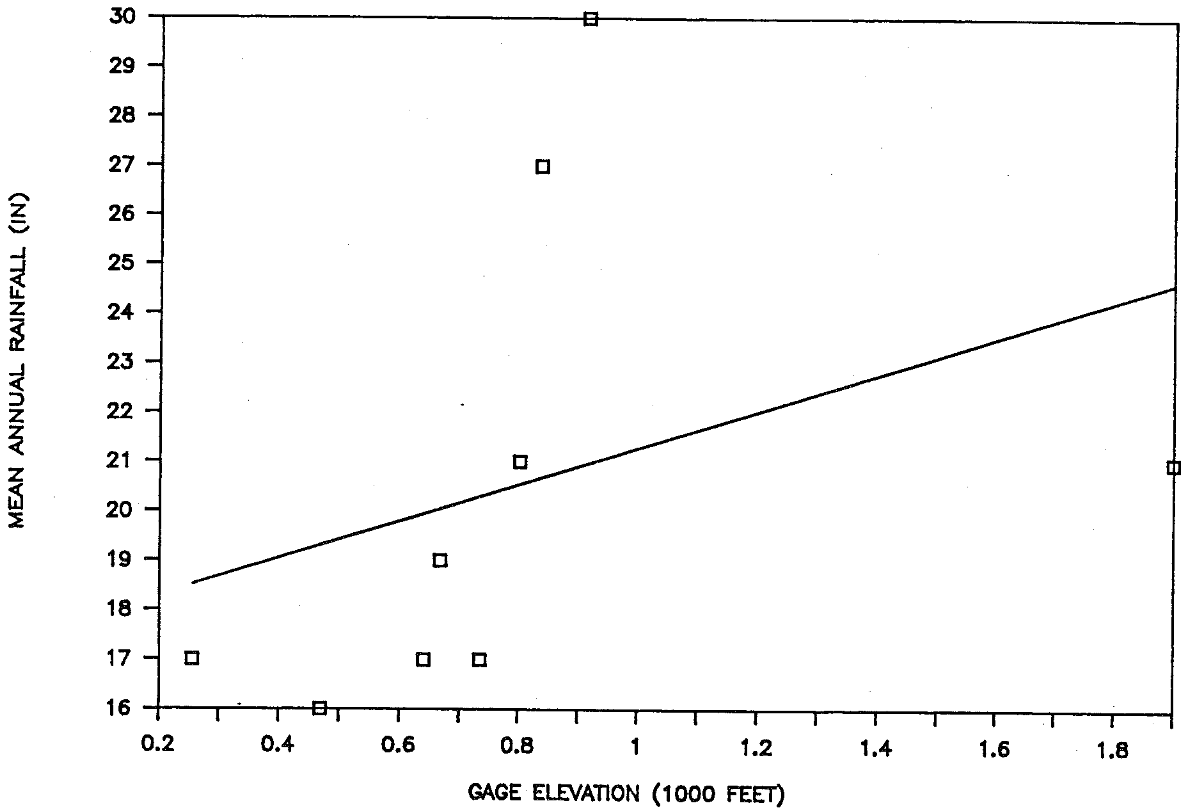


Figure 5-3b. MEAN ANNUAL RAINFALL VS. ELEVATION, DIABLO RANGE

range from 15 inches in the foothills to 36 inches at 3800 feet (MSL). In the Diablo Range, the effect of elevation on mean annual precipitation is less pronounced, perhaps due to the lower elevations of these gages (200 to 1800 feet MSL) and the loss of air moisture through precipitation in the Santa Cruz Mountains.

5.1.2.2 Seasonal and Annual Variability of Rainfall Volumes. This section addresses the variability of rainfall over time, including the seasonal distribution of rainfall and the variability of annual rainfall volumes. The analysis focuses on the rainfall data for the National Weather Service gage in San Jose because of the length of record available (hourly data from 1948-1989) and the high precision of the data (to one-hundredth of an inch).

Figure 5-4 is a plot of monthly average rainfall for the National Weather Service rain gage in San Jose, and illustrates the seasonal pattern of rainfall in the Santa Clara Valley. In general, most of the rainfall occurs during a distinct rainy season spanning the months of October through April. At the San Jose gage, an average of 13 out of the 14 inches of rainfall measured annually occurs during this rainy season. January receives the highest monthly volume on average, while July receives the lowest.

Figure 5-5 is a time series plot of wet-season rainfall for 1948 through 1989. Note that these annual volumes are computed on a wet-season basis (October 1 through April 30). Rainfall at the gage varies greatly from year to year; the minimum recorded annual total is 4.9 inches in 1975-76, while the maximum recorded total is 30 inches in 1982-83. The average wet-season rainfall total is 13 inches. A lognormal probability plot of the wet-season volumes is shown on Figure 5-6. The data are well represented by a lognormal probability distribution, with a correlation coefficient of 0.992 for the lognormal fit. Wet-season rainfall is greater than or equal to 20 inches in 10 percent of the years, and is greater than or equal to 7 inches in 90 percent of the years.

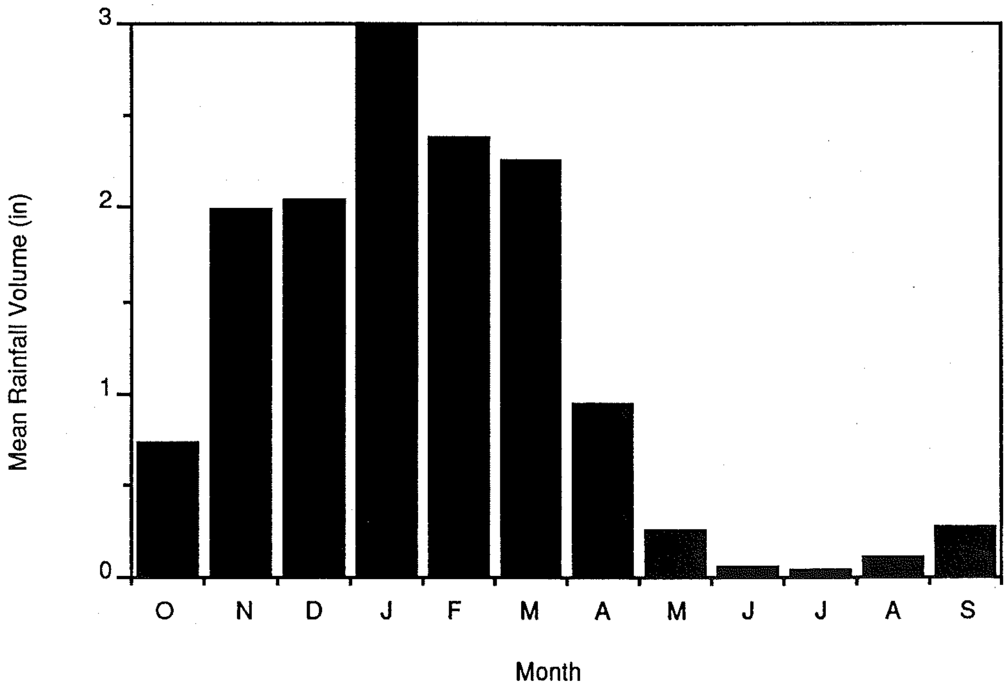


Figure 5-4. Average Monthly Rainfall Volumes, San Jose NWS Gage

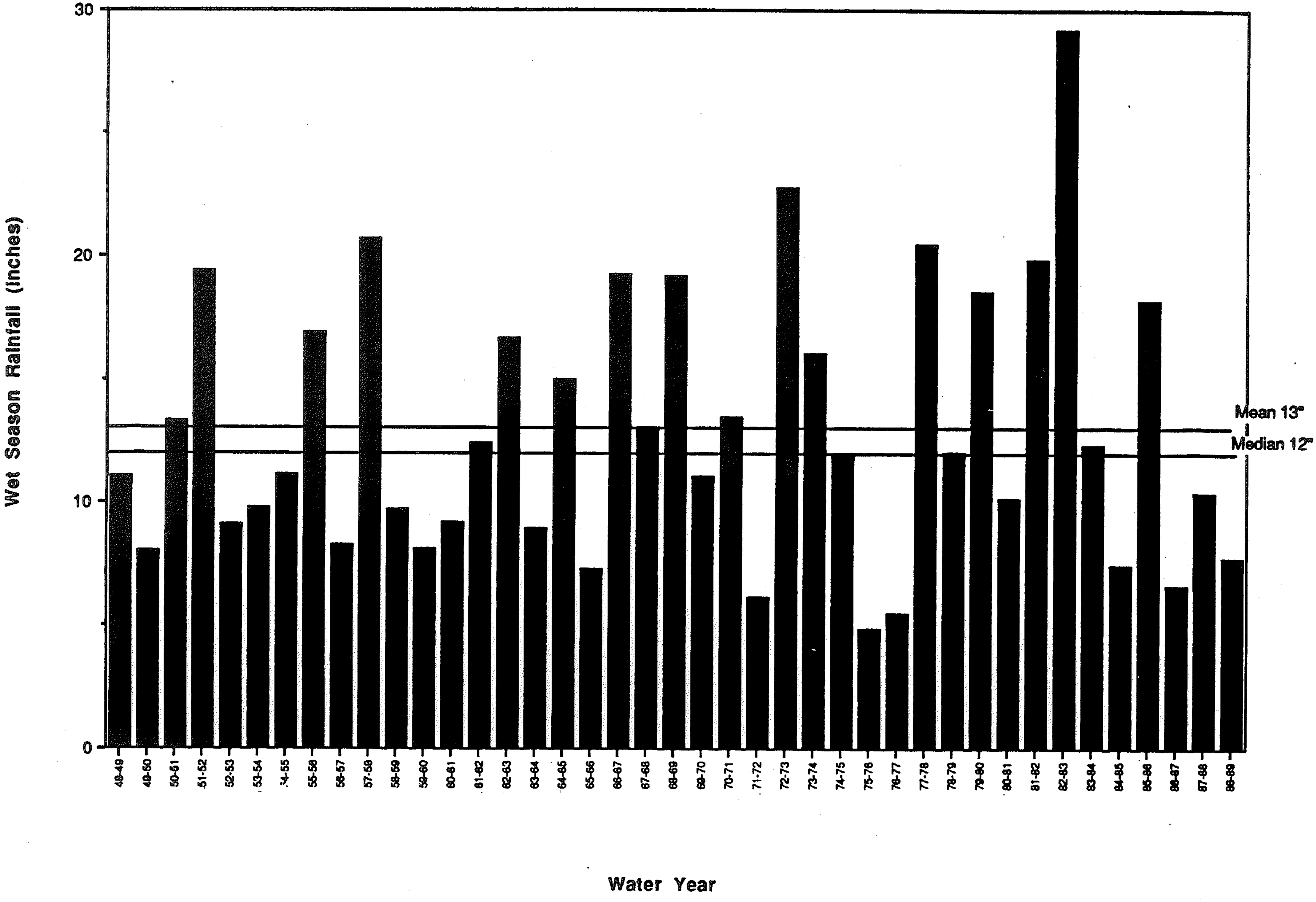


Figure 5-5. WET SEASON RAINFALL AT THE SAN JOSE NWS GAGE

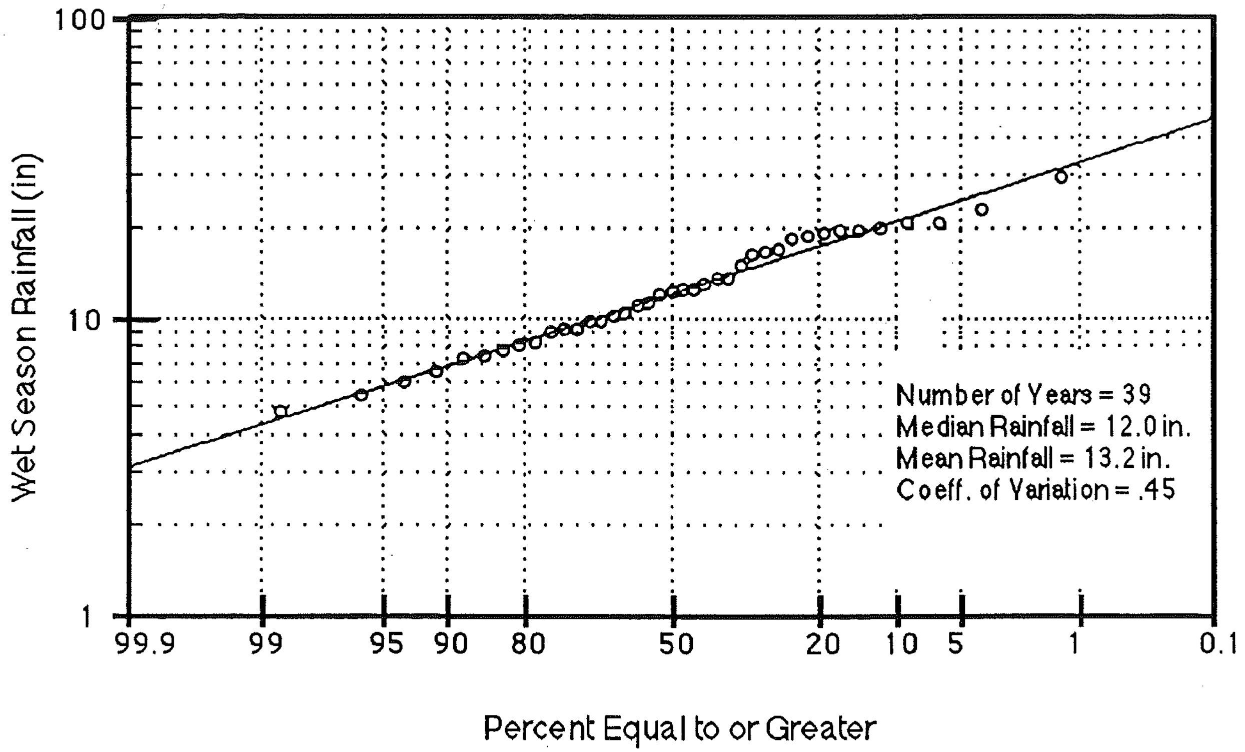


Figure 5-6. Log Probability Plot of Wet Season Rainfall,
San Jose NWS Gage

The frequency distribution of wet-season rainfall volumes is particularly important in selecting representative periods for calibrating the hydrologic model and for projecting annual water quality loads. In general, most of the continuous rainfall records in the valley begin after 1970, and the spatial distribution of operating gages improved in 1974. Thus, calibration and projection periods were selected between 1974 and 1989. The representativeness of this period can be checked by comparing its statistics with those of the complete period of record for the San Jose National Weather Service gage. The mean wet-season rainfall volume from 1974 to 1989 is 13 inches, which is approximately equal to the average for the entire period of record. The 1974-1989 period contains the highest annual total recorded (30 inches in 1982-83) and also includes the 2-year drought of 1975-76 and 1976-77. Thus, the 1974-89 period, although average in terms of mean annual volumes, contains a wide range of annual rainfall conditions, including the wettest and driest years of record. This wide range of annual rainfall conditions provided for robust model calibrations.

5.1.2.3 Storm Event Statistics. This section focuses on statistics of individual storm events in the Santa Clara Valley, as the storm event drives the runoff process. Events are described in terms of volume, duration, intensity, and time between storms. The information provided here will later be used to address the representativeness of the storm events monitored in this study.

The statistical characteristics of storm events in the valley were analyzed using the Synoptic Precipitation Analysis Program SYNOP (WCC 1980). The program segregates hourly rainfall records into discrete storm events by defining the minimum number of dry hours required to distinguish between consecutive storms. This minimum number of dry hours, referred to as the minimum interevent time, is estimated such that the coefficient of variation of all interevent times is close to 1.0 (based on the assumption that interevent times follow a gamma frequency distribution). Once storm events are segregated, the program performs a standard statistical analysis of storm volume, duration, intensity, and interevent time. Statistics are calculated annually, monthly, and for the entire period of record.

For the Santa Clara Valley, SYNOP was applied to the San Jose National Weather Service record for the period 1948 to 1989. The analysis was performed for the October-through-April wet season only, since the long dry periods in the dry season would bias the determination of the minimum interevent time. Table 5-1 presents the SYNOP summary statistics for storm event volume, duration, and interevent time over the entire period of record. The minimum interevent time was estimated as 24 hours, or 1 day. On average, there were 17 storms per wet season, with an average volume of 0.72 inch and duration of 31 hours. The average interevent time was 10 days. Storms were highly variable, and the coefficients of variation (standard deviation/mean) for volume, duration, and interevent time were all greater than or equal to 1.0.

Figure 5-7 shows the monthly distribution of average storm volumes and number of storms over the wet season. By comparing this figure to the monthly rainfall volumes shown in Figure 5-4, it can be seen that the wettest month (January) is also the month with the largest and most-frequent storms. Conversely, the driest month in the wet season (October) has the second-smallest average storm volumes and the least-frequent storms.

To gain insight into the frequency of storm volumes, all storm events for the period of record were ranked and plotted on the log-probability plot shown in Figure 5-8. The data are well represented by a lognormal distribution, with a correlation coefficient of 0.99 for the fit. The median storm-event volume is 0.49 inch. The storm-event volume that has a 10 percent exceedance probability is 1.5 inches (i.e., 10 percent of the storms are greater than or equal to 1.5 inches).

Table 5-1. WET-SEASON STORM EVENT STATISTICS FOR NATIONAL WEATHER SERVICE SAN JOSE GAGE

	Average	Coefficient of Variation	Minimum	Maximum
Storm Volume (inches)	0.72	1.1	0.11	6.0
Duration (hours)	31	1.0	1.0	312
Intensity (inches/hour)	0.04	1.6	0.003	0.92
Interevent Time (days)	10	1.0	1	62

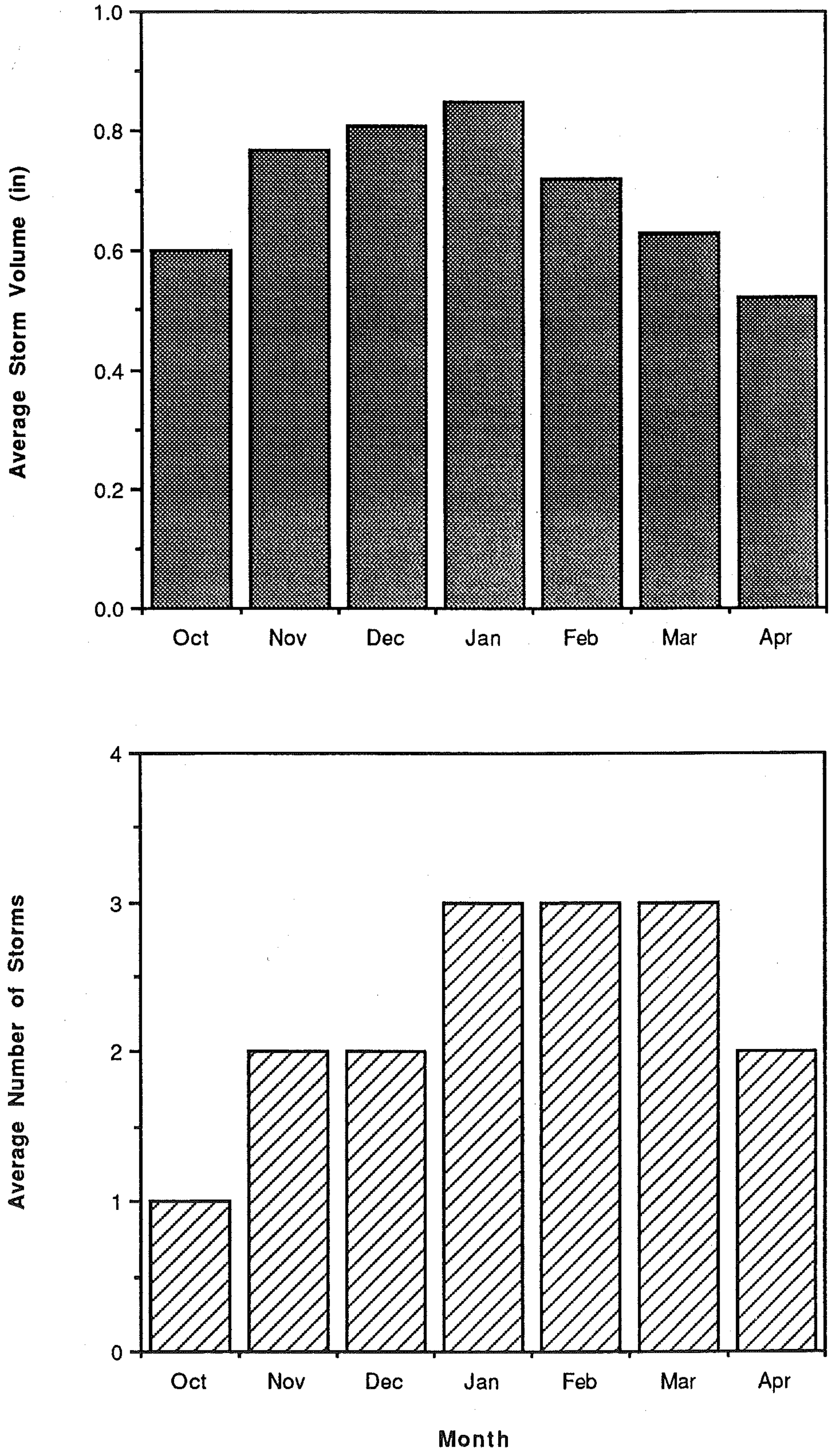


Figure 5-7. Monthly Average Storm Characteristics (San Jose NWS Gage, 1948-89)

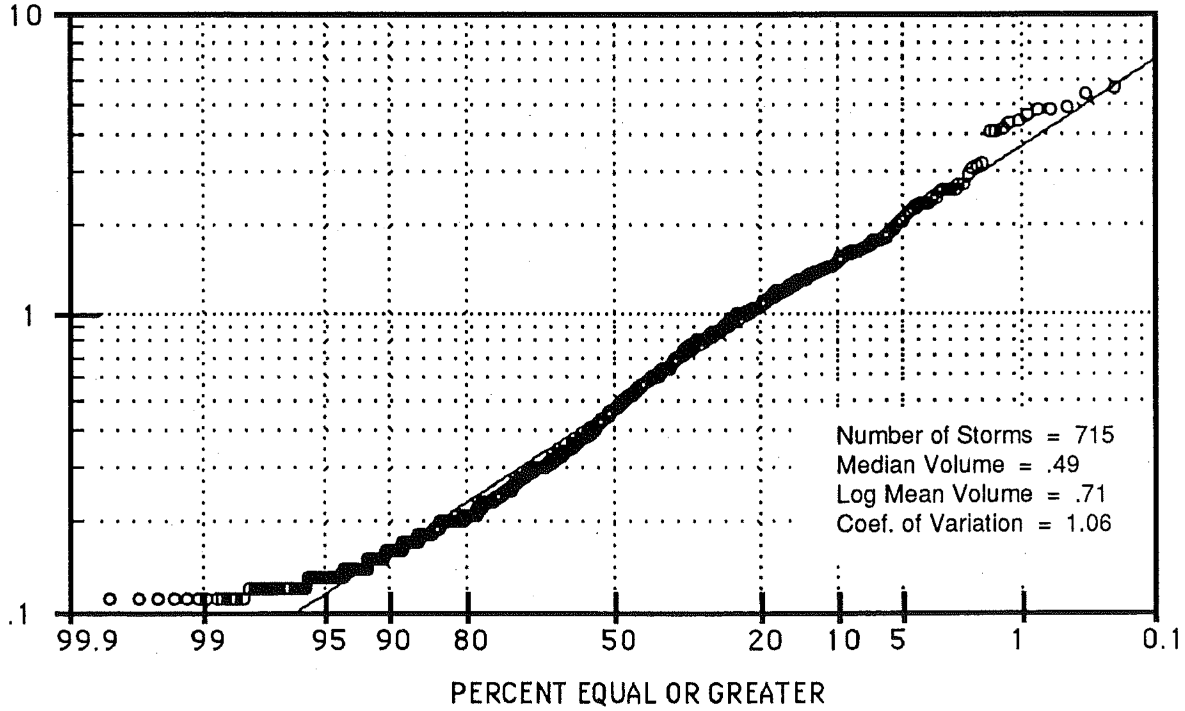


Figure 5-8. Log Probability Plot of Storm Volumes,
San Jose NWS Gage

5.1.3 Storm Events During the 1988-89 Sampling Period

Water quality data collected in this study were used to characterize nonpoint source loads for other years (Section 8.0). Thus, it is important to address the representativeness of the 1988-89 sampling period in terms of rainfall and runoff. This section presents the rainfall statistics for the 1988-89 wet season (during which most of the wet-weather data were obtained), and compares these statistics to those for the period of record at the San Jose National Weather Service (NWS) gage.

1988-89 was a relatively dry year, with only 7.66 inches of rain recorded at the San Jose NWS gage during the wet season (this is approximately 6 inches below average). The previous year was also drier than normal, with only 10 inches of rainfall. The number of storms in 1988-89 (15) is comparable to the wet-season average (17), but the average storm volume was 0.49 inch, or 0.23 inch smaller than the average storm volume for the period of record. The largest storm of 1988-89 was 1.08 inches on December 20. Figure 5-9 shows the monthly distribution of rainfall over the period; 30 percent of the total rainfall for the season occurred in December.

Table 5-2 summarizes the storms for which water quality data were collected for this study. These data include one storm in April 1988 and six storms in the 1988-89 wet season. The sampled storms include the first large storm of 1988-89 (November 23) and the last major storm of the season (March 23). The sampled storms range in volume from 0.11 to 0.67 inch, with an average of 0.36 inch, compared to average storm volumes of 0.49 inch for 1988-89 and 0.72 inch for the San Jose National Weather Service gage period of record. Relative to the frequency distribution of storm volumes at the San Jose NWS gage (see Figure 5-8), the sampled storm volumes were less than or equal to the 60th percentile.

In summary, the 1988-89 period was drier than average, but the storms sampled were fairly typical for that year in terms of volume, duration, and

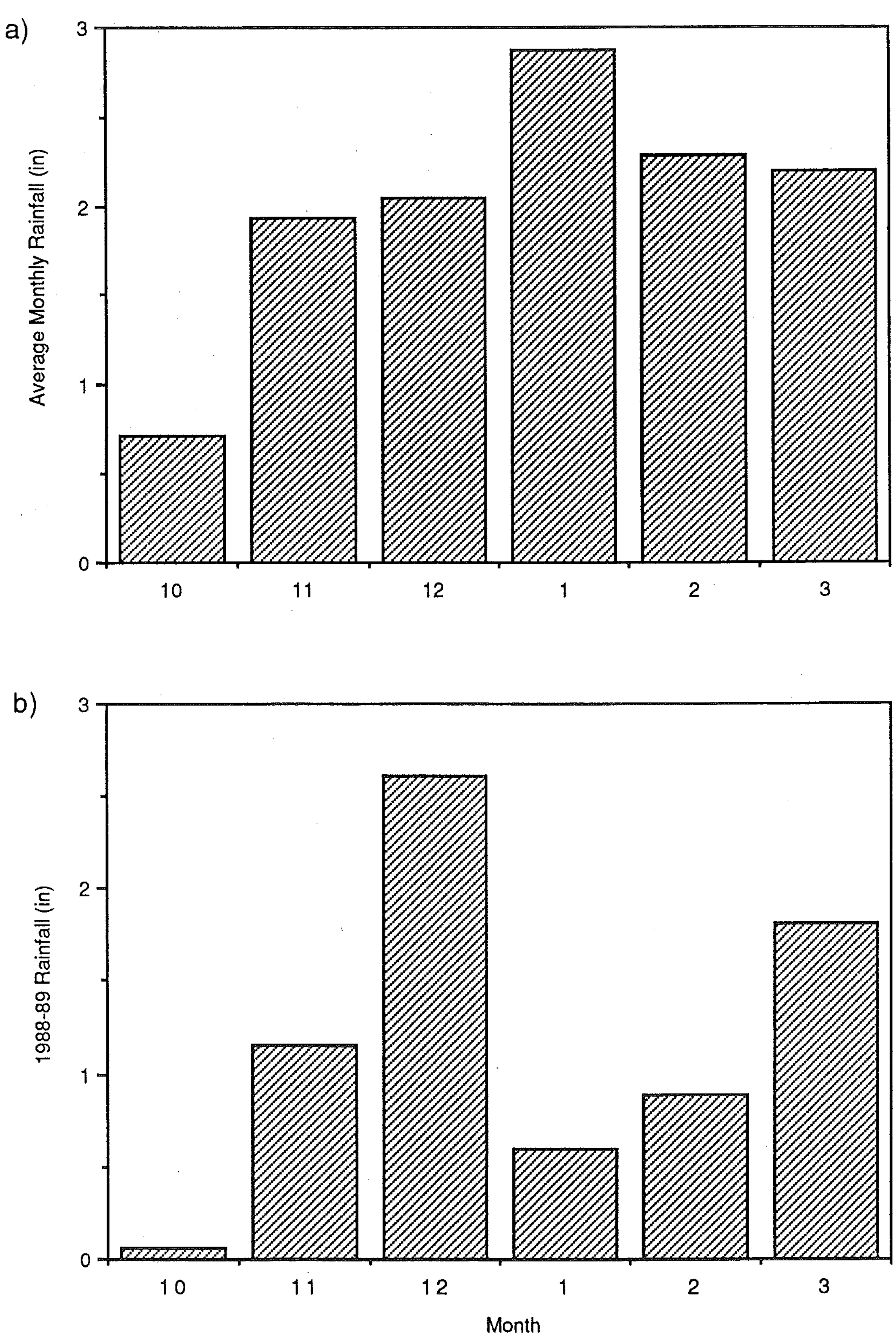


Figure 5-9. Monthly Rainfall at the San Jose NWS Gage for a) Average Year (1948-89), and b) the 1988-89 Wet Season

Table 5-2. PRECIPITATION DATA FOR STORMS SAMPLED IN 1988-89

Sampling Date	Volume (inches)	Percentile*	Duration (hours)
4/20/88	.30	30	18
11/23/88	.67	60	5
1/23/89	.38	40	9
2/1/89	.34	35	20
2/8/89	.52	52	11
3/2/89	.11	5	6
3/23/89	.22	17	3
Mean	.36		10
Coefficient of Variation	.51		0.63
Minimum	.11		3
Maximum	.67		20

Note: Storm data are from San Jose NWS gage.

* Probability that storm volume will be less than or equal to observed based on storm-event frequency distribution (Figure 5-8).

interevent time. The volumes of the storms sampled were generally less than the long-term median volume.

5.2 RUNOFF

This section focuses on existing streamflow data in the Santa Clara Valley. Section 5.2.1 describes the existing streamflow monitoring network in the valley, including periods of record and the locations of stream gages. Section 5.2.2 presents an analysis of some historical streamflow data, and provides insight into the annual and seasonal variability of runoff. Finally, Section 5.2.3 summarizes the hydrologic data collected during the 1988-89 sampling period for this study.

5.2.1 Streamflow Monitoring Network

Table 5-3a summarizes the stream gages operating on creeks and rivers in the Santa Clara Valley, and Figure 5-10 shows the locations of stream gages. Most of these are stage recording gages operated by the Santa Clara Valley Water District (SCVWD 1982b). In addition, the U.S. Geological Survey (USGS) has stage recording gages on the Guadalupe River, Coyote Creek, Saratoga Creek, and Upper Penitencia Creek. Periods of record in the valley are variable, but most of the gages were in service by 1975. The longest records are for the USGS gages on Coyote Creek and the Guadalupe River.

The quality of the SCVWD rating curves and discharge measurements has been extensively reviewed in a report by Kennedy/Jenks/Chilton (1986). Rating curves used by the SCVWD were found to be of generally good quality, although discharge measurements used in generating the rating curves were usually poor to fair (based on USGS measurement criteria). However, significant errors were found in the computation of flows by SCVWD's Burroughs computer system, indicating that rating curves were not applied correctly. The SCVWD has since switched to a new data management system, and has resolved these problems.

Table 5-3a. STREAM GAGE INFORMATION

Stream	Gage No.	Period of Record	Drainage Area (sq. mi)	Gage Operator
Permanente Creek	32a	1975-	8.2	SCVWD
	37	1961-1983	8.8	SCVWD
Hale Creek	33	1976-	2.7	SCVWD
Stevens Creek	44	1930-	18.0	SCVWD
	35	1938-	25.0	SCVWD
Guadalupe Slough inflows				
-Sunnyvale E. Channel	74	1977-	7.3	SCVWD
-Calabazas Creek	31	1966-	4.6	SCVWD
	26a	1976-	13.6	SCVWD
-Saratoga Creek	25	1966-	15.1	SCVWD
	169500	1933-	9.2	USGS
-San Tomas Aquinas Creek	29	1945-	3.6	SCVWD
	24	1963-	13.4	SCVWD
Guadalupe River Basin				
-Calero Creek	14	1938-	0.9	SCVWD
	13	1939-	7.1	SCVWD
-Alamitos Creek	16	1938-	12.1	SCVWD
	70	1975-	31.8	SCVWD
-Ross Creek	21	1945-	2.2	SCVWD
	51	1968-	7.6	SCVWD
-Los Gatos Creek	67	1971-	40.0	SCVWD
	59	1967-	44.2	SCVWD
	50	1955-	50.0	SCVWD
-Guadalupe River	17	1941-	5.9	SCVWD
	43	1915-	12.5	SCVWD
	20	1940-	54.1	SCVWD
	23b	1975-	66.8	SCVWD
	169000	1929-	145.9	USGS
-Canoas Creek	73	1977-	18.6	SCVWD
Coyote Creek Basin				
-Las Animas Creek	56	1961-	37.0	SCVWD
-Packwood Creek	57	1961-	10.0	SCVWD
-Coyote Creek	12	1958-	120.0	SCVWD
	9	1951-	194.0	SCVWD
	170000	1916-	196.0	USGS
	58	1916-	229.0	SCVWD
-Fisher Creek	10	1942-	14.1	SCVWD
-Thompson Creek	75	1980-	18.1	SCVWD
-Upper Penitencia Creek	172100	1961-	21.5	USGS
	1	1938-	22.6	SCVWD
	2	1947-	24.2	SCVWD
-Berryessa Creek	64	1969-1983	15.1	SCVWD

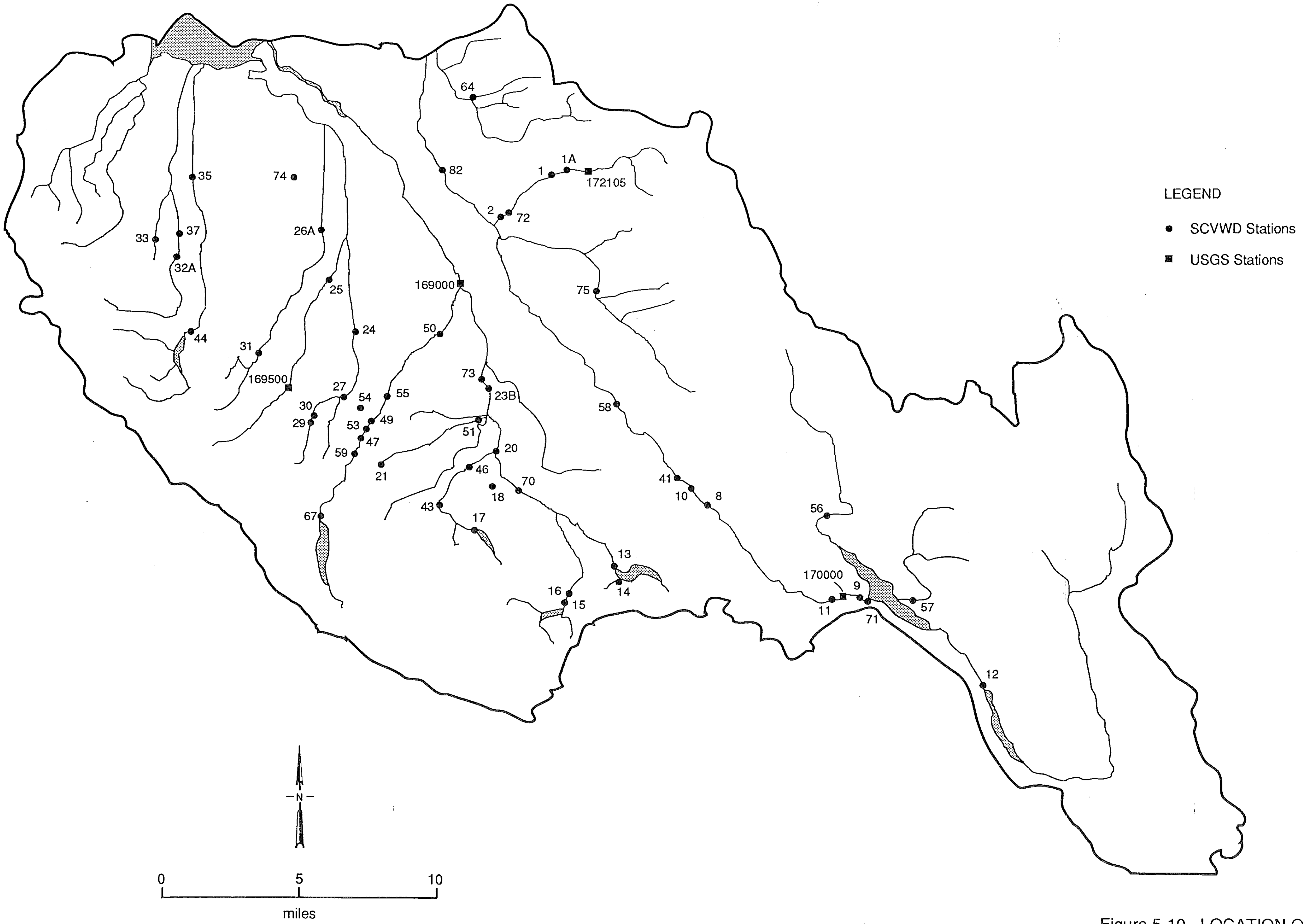


Figure 5-10. LOCATION OF STREAMFLOW GAGING STATIONS

In those cases where a sampling station was not located at an SCVWD or USGS gage, the station was rated specifically for this study using USGS-recommended procedures. In manholes, rectangular-notched weirs were used to measure flow. At other stations, rating curves were developed from measured discharges. Although discharge measurements for this study were generally good, rating curves are at best fair due to the limited number of discharge measurements conducted at each station. Rating curves developed for this study are summarized in Appendix A.

The SCVWD has an extensive water supply distribution and reservoir system, and most of the stream gages are located to aid in operating this system. Thus, gages tend to be concentrated above and below the groundwater recharge ponds and reservoirs on Los Gatos Creek, Guadalupe River, and Coyote Creek. At least one gage is located immediately below each of the reservoirs on Stevens Creek, Guadalupe Creek, Los Gatos Creek, and Calero Creek. No gages are situated far enough downstream to measure total discharges into the Lower South Bay, but the downstream gages on Stevens Creek, Sunnyvale East Channel, Calabazas Creek, Saratoga Creek, Guadalupe River, Upper Penitencia Creek, and Berryessa Creek do represent most of the drainages area for these streams. Large areas of the basin are entirely ungaged, especially the lower portion of Coyote Creek and the smaller streams in the western part of the valley.

5.2.2 Analysis of Historical Streamflow Records

This section reviews seasonal historical streamflow records to provide insight into the variability of runoff on an annual and seasonal scale. Table 5-3b lists mean and maximum daily average flow rates for selected stream gages in the Santa Clara Valley. The largest streams in the basin are the Guadalupe River and Coyote Creek. However, the smaller basins in the western part of the County generate more runoff per unit area, primarily because of the higher rainfall received in these basins.

Table 5-3b. STREAMFLOW STATISTICS FOR SELECTED STREAMGAGES

Stream	Gage No.	Period	Drainage Area (sq. mi.)	Mean Flow Rate (cfs)	Maximum Daily Avg. Flow (cfs)
Stevens	35	1974-1989	25	17.5	1100
Sunnyvale E.	74	1977-1989	7.3	2.16	196
Calabazas	26a	1975-1988	14	4.75	876
Saratoga	25	1974-1989	15	12.1	2000
San Tomas Aq.	24	1972-1989	13	8.58	1000
Guadalupe	169000	1974-1989	146	60.5	6700
Berryessa	64	1970-1983	15	3.66	219

For long-term trends, the analysis focuses on the record for the Guadalupe River USGS gage. This record dates back to 1929 and is generally rated as good (USGS 1982). The upstream drainage area is 146 square miles, and represents most of the drainage area for the Guadalupe River. This area is composed of a large variety of land uses, including flat urban areas in San Jose and steep open areas in the Santa Cruz Mountains. Flow is regulated upstream by several water supply reservoirs and recharge ponds.

Figure 5-11 is a time series plot of annual runoff measured at the Guadalupe River gage from water years 1930-1988. Annual runoff during this period ranged from 0.04 to 25 inches, with a mean value of 3.7 inches. These data have a coefficient of variation of 1.3, indicating that runoff volume varies greatly from year to year. To gain insight into this annual variability, Figure 5-12 presents a plot of annual rainfall versus annual runoff coefficient (annual runoff/annual rain) using rainfall from the San Jose National Weather Service gage. This figure shows that during dry years considerably less runoff is produced per unit rainfall than in wet years. Thus, the variability in annual runoff reflects variability in rainfall plus the variability in runoff-producing mechanisms (e.g., effects of antecedent soil moisture conditions on infiltration) between wet and dry years.

The Guadalupe River basin has changed considerably since 1929, with agricultural and open land being developed into residential and commercial land uses. Urbanization alters the runoff characteristics of the catchment, due to increased impervious area and stormdrain networks. This effect can be seen by comparing data from the last 15 years to the entire data set. The mean annual runoff coefficient relative to the San Jose NWS gage for the 1974-89 period was .34, or 40 percent higher than the mean for 1948-89. An important implication of this is that data from the early part of the record should not be used for projections of future runoff and water quality loads.

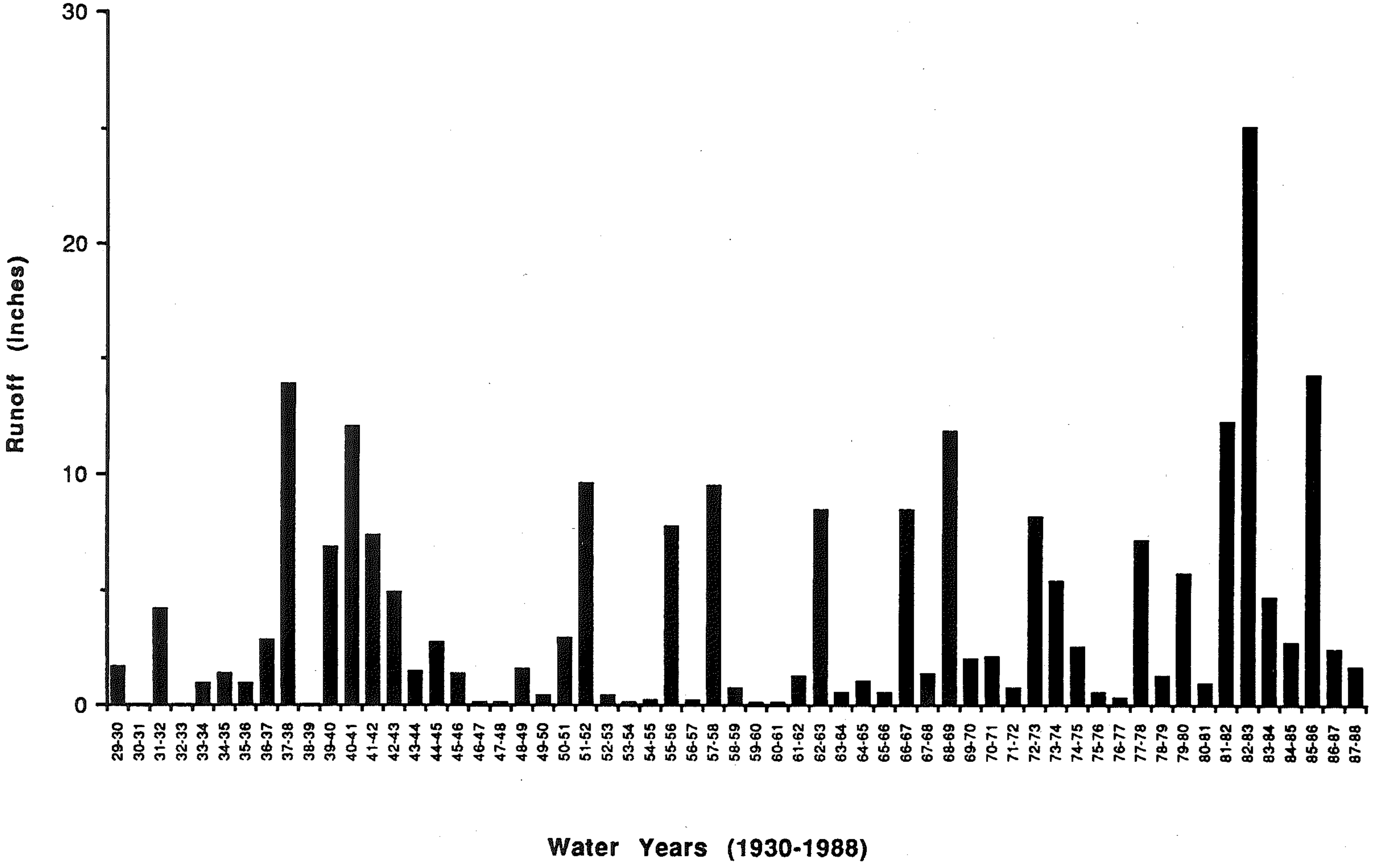


Figure 5-11. Annual Runoff at Guadalupe River Gage 11169000

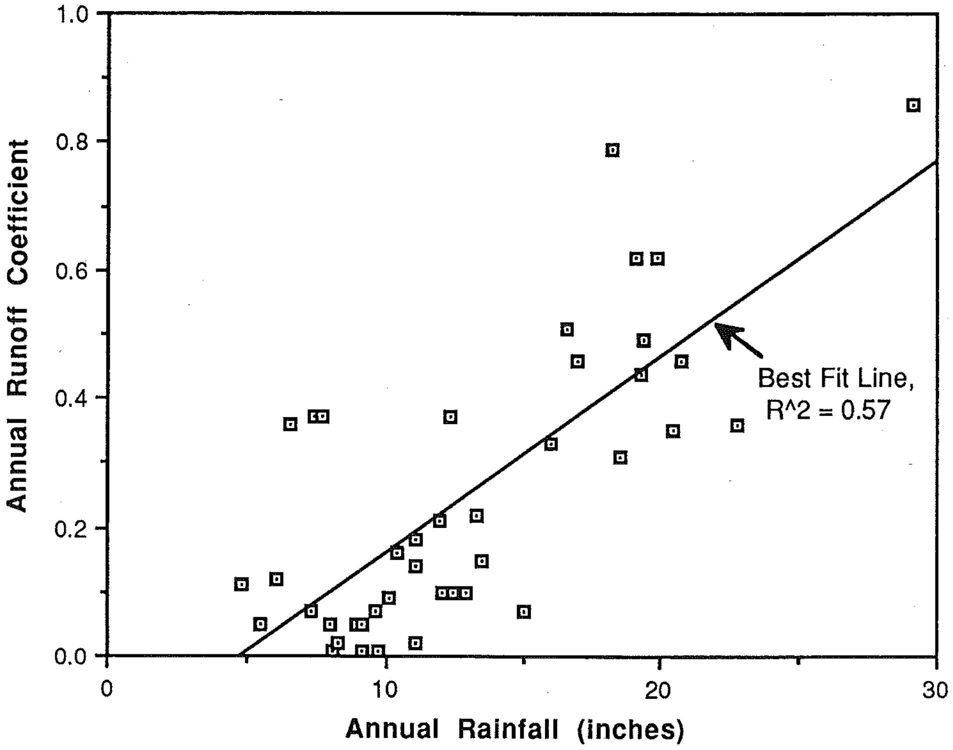


Figure 5-12. Annual Runoff Coefficient as a Function of Rainfall, Guadalupe River (1930-1988)

To examine seasonal variability of runoff, an analysis was performed on monthly streamflow data for Calabazas Creek. Unlike the Guadalupe River, flows in Calabazas Creek are not regulated by reservoirs or recharge ponds, thus ensuring that any observed seasonal runoff patterns will not be affected by reservoir storage and releases. Calabazas Creek also has two streamflow gages, one representing upstream open and low-density residential areas, and a downstream gage representing mixed urban land uses (Gages 31 and 26a in Figure 5-10). Figure 5-13 shows monthly average runoff volumes and runoff coefficients for the period of record at the downstream gage. On average, the highest runoff volumes and runoff coefficients occur in the months with the highest rainfall (January and February). Runoff coefficients are also higher in the late season (March and April) than in November and December, perhaps due to higher antecedent soil moisture conditions in March and April. Figure 5-14 shows the percent contribution by month of the relatively undeveloped upstream area to runoff at the downstream gage. In the early season (November and December), the less urbanized areas contribute only 30 to 40 percent of the total runoff volume. Later in the season, this contribution increases to 50 to 60 percent. The 50 percent contribution in October does not appear to follow this seasonal pattern; however, streamflow volumes for this month are typically small (0.10 inch on average) and are strongly influenced by dry-weather flows (i.e., natural baseflow, water supply releases, point source discharges).

5.2.3 Runoff During the 1988-89 Sampling Period

The 1988-89 sampling period was a dry year in terms of both rainfall and runoff. On the Guadalupe River, the seasonal runoff volume through March 1989 was 0.21 inches, or 3.5 inches below normal. Figure 5-15 is a plot of daily flows on the Guadalupe River for the period, and shows the hydrographs for the sampled events. The season consisted of several small events in late October followed by a large storm on November 23. The next major runoff events occurred in late December, accounting for 30 percent of the total runoff for 1988-89. January and February were relatively dry, but were followed by large storms in March. Water quality for none of the

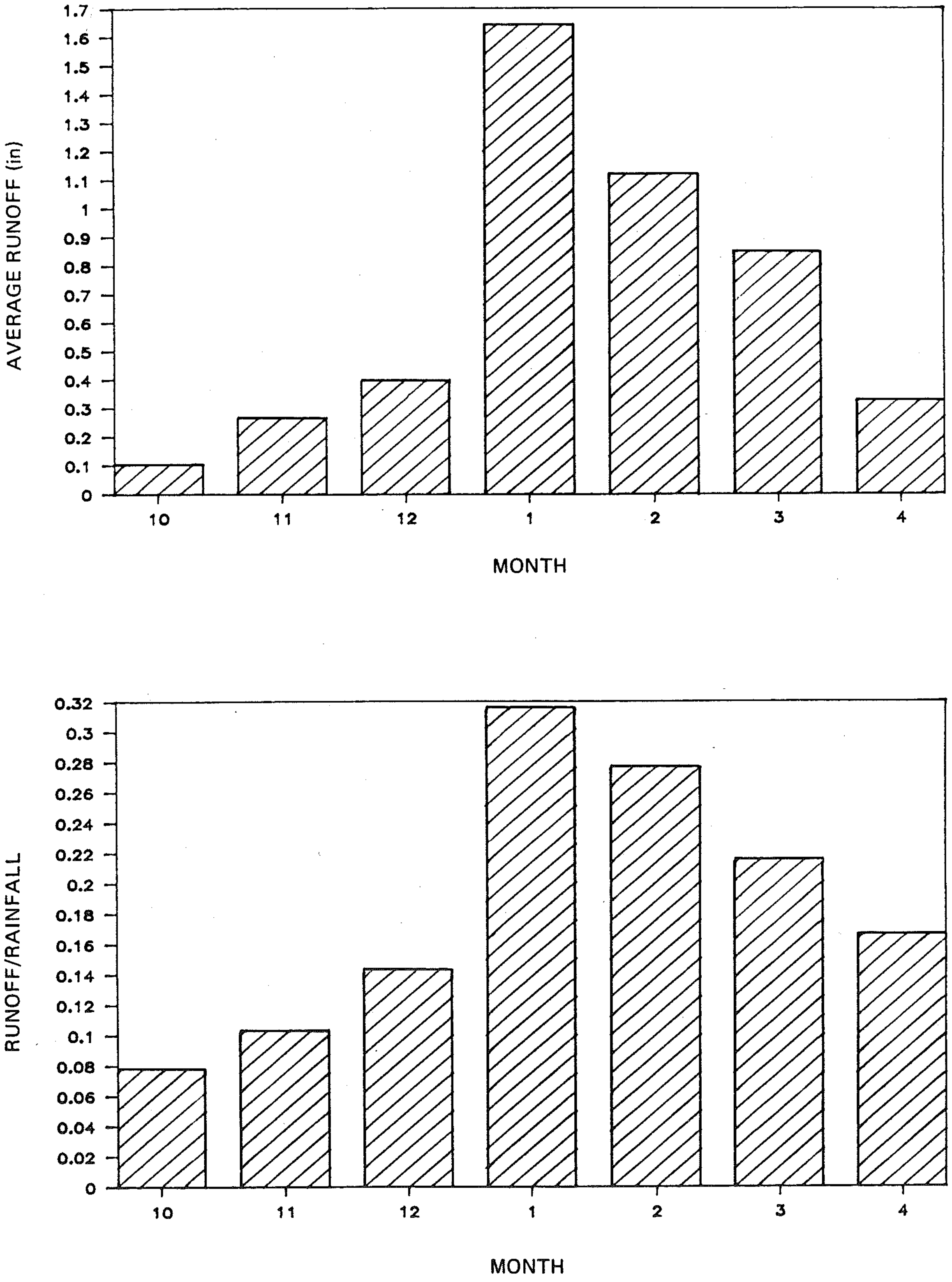


Figure 5-13. MONTHLY AVARAGE RUNOFF VOLUMES AND RUNOFF COEFFICIENTS FOR CALABAZAS CREEK, DOWNSTREAM GAGE 26a

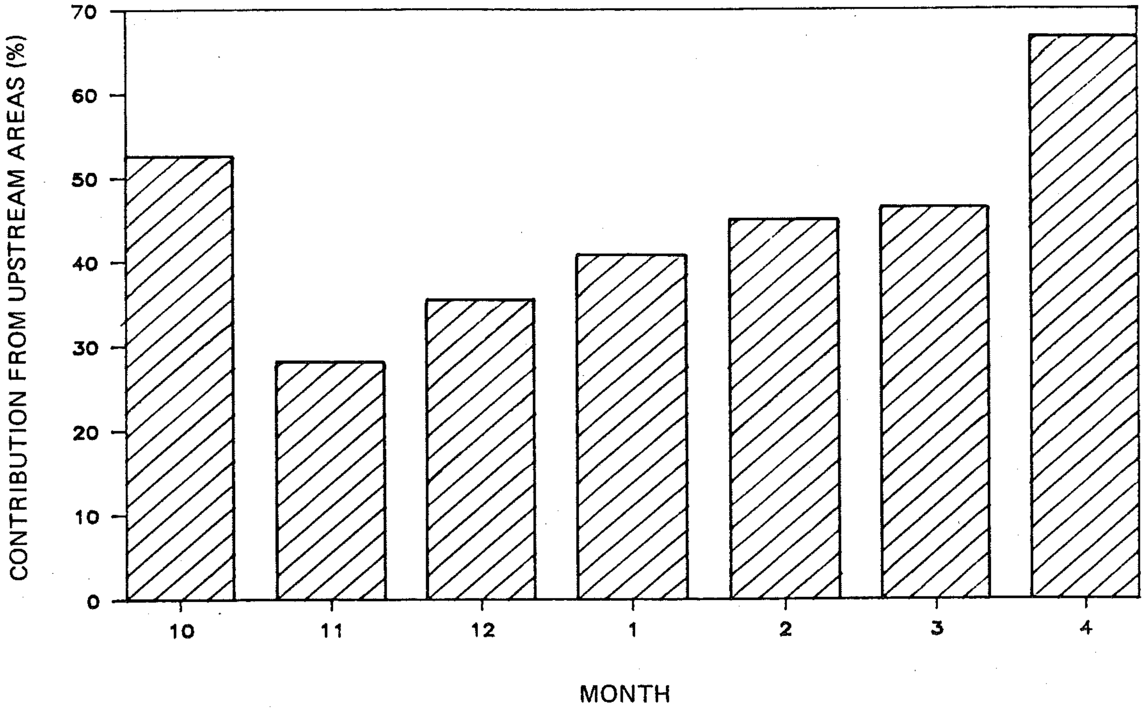


Figure 5-14. MONTHLY PERCENT CONTRIBUTION OF STREAMFLOW AT UPSTREAM GAGE 31 TO STREAMFLOW AT DOWNSTREAM GAGE 26a ON CALABAZAS CREEK

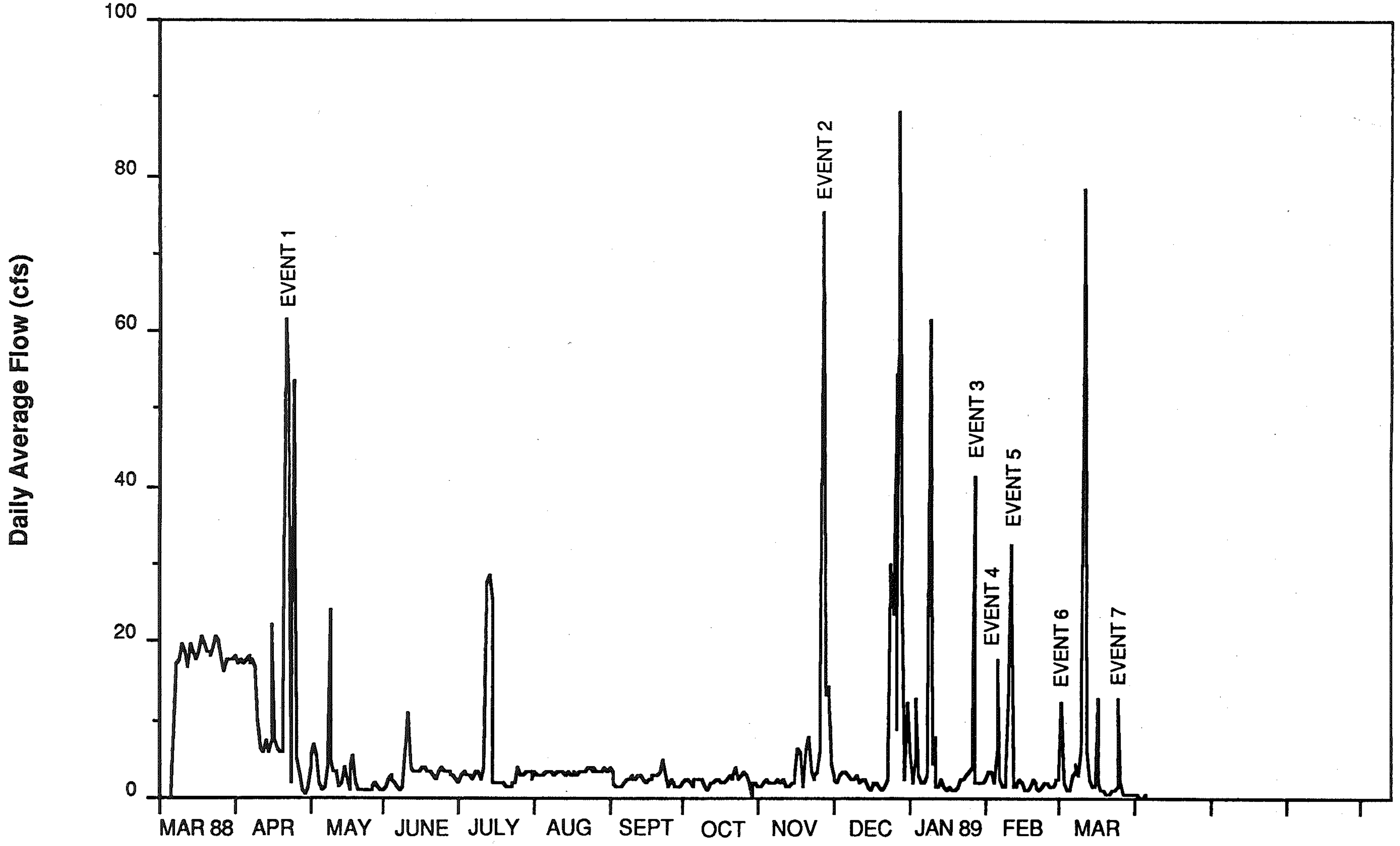


Figure 5-15. Guadalupe River Hydrograph for 1988-89 Sampling Period

December storms was sampled, but the remainder of the season is well represented with one sampled storm in November, one in January, two in February, and two in March.

Water quality data was collected at two types of stations: (1) stream stations, representing large multiple land use catchments; and (2) land use stations, representing small uniform land use catchments. The measured hydrology of these two types of stations are discussed separately in the following two sections.

5.2.3.1 Stream Station Hydrology. Stream stations were installed at existing gages on the Guadalupe River, Calabazas Creek, Coyote Creek, and Sunnyvale East Channel (Figure 4-1). Table 5-4 summarizes the runoff coefficients for each of the sampled events at these stations. Note that these runoff coefficients are calculated based on rainfall measured at the San Jose National Weather Service Gage. This rainfall underestimates rainfall for those catchments which extend up into high-rainfall areas in the Santa Cruz Mountains and the Diablo Range (particularly for Coyote Creek and the Guadalupe River). However, these runoff coefficients can be used for comparisons between watersheds, recognizing that the actual values of the coefficients are overestimated. In general, the highest runoff coefficients were on the catchments which drain mostly urban areas (Sunnyvale East and Calabazas Creek). Coyote Creek and the Guadalupe River have large undeveloped areas in the Santa Cruz Mountains and the Diablo Range, and consequently generate less runoff per unit rainfall volume.

Figure 5-16, a typical event hydrograph for Calabazas Creek, illustrates several common features of storm hydrographs in the Santa Clara Valley. The initial storm response is rapid and strong, with the hydrograph peak occurring soon after the peak rainfall intensity. The initial recession of this hydrograph is also rapid (within 1 day), but is followed by a slower recession at low flows which continues for 2 to 3 days. This hydrograph configuration gives some indication of the processes which generate runoff from rainfall. The initial rapid rise and fall implies

Table 5-4. RUNOFF CHARACTERISTICS FOR EVENTS SAMPLED AT STREAM STATIONS

Station	Event	Runoff Volume (inches)	Runoff* Coefficient (runoff/rainfall)
Calabazas Creek (S1)	1	.07	.1
	2	.27	.4
	3	.01	.03
	4	.03	.09
	5	.06	.12
	6	.02	.18
	7	.05	.23
Sunnyvale East Channel (S2)	1	.06	.09
	2	.11	.16
	3	.06	.16
	4	.09	.26
	5	.19	.37
	6	.06	.55
	7	.13	.59
Guadalupe River (S3)	1	.03	.04
	2	.02	.03
	3	.01	.03
	4	.01	.02
	5	.01	.02
	6	.004	.04
	7	.004	.02
Coyote Creek (S4)	1	.01	.01
	2	.03	.04
	4	.01	.03
	5	.01	.02
	6	.003	.03
	7	.002	.01

* Based on San Jose National Weather Service gage rainfall, which is not necessarily representative of actual rainfall, especially for Guadalupe River and Coyote Creek.

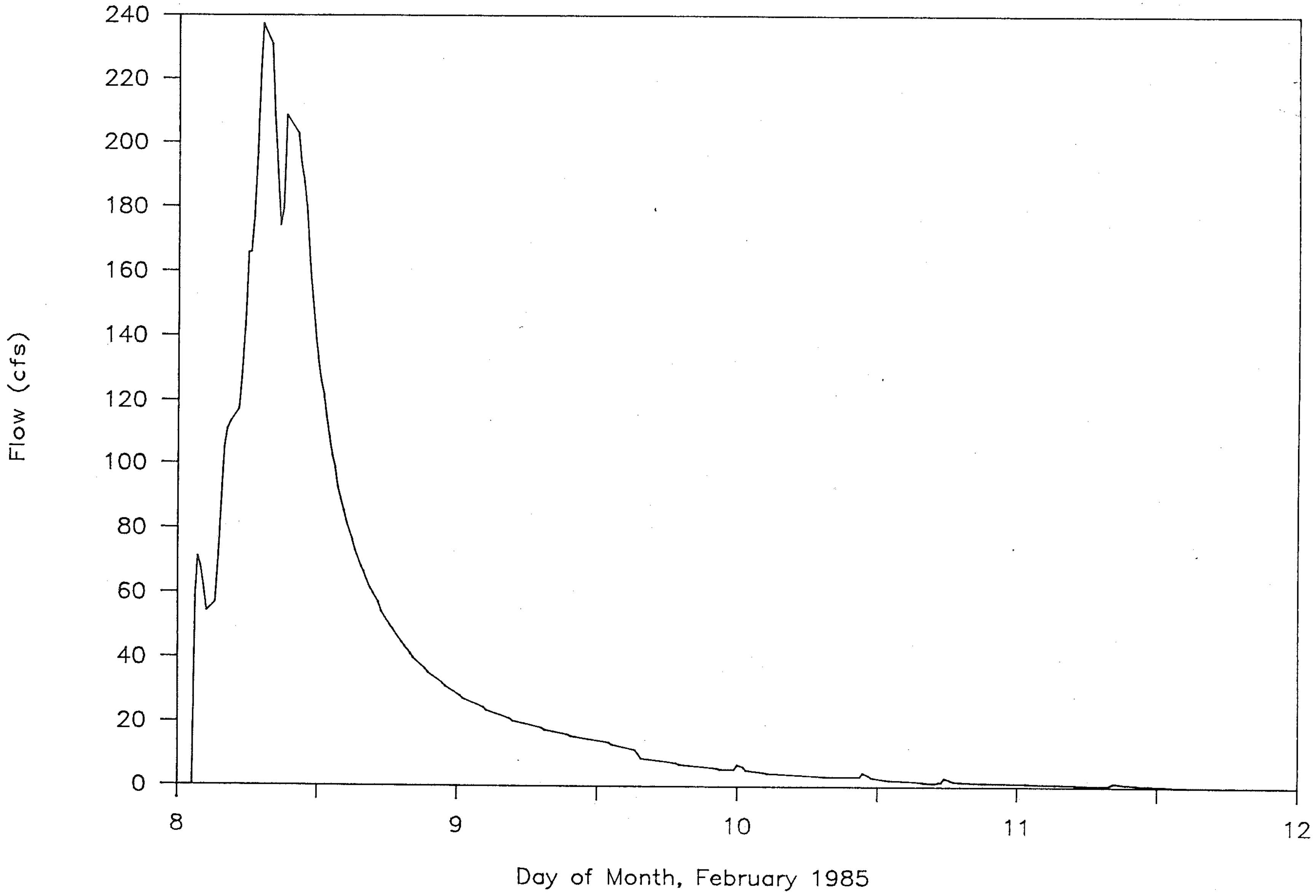


Figure 5-16. TYPICAL STORM HYDROGRAPH, CALABAZAS CREEK

that storm response consists primarily of surface runoff. This surface runoff could originate from impervious areas or from pervious areas that are saturated or have infiltration rates lower than the rainfall intensity. The longer-term recession which follows the storm hydrograph indicates that there is also some storage and release of infiltrated stormwater in the soil. In most of the Santa Clara Valley the water table is below the streambeds, indicating that this recession consists of interflow through the unsaturated zone, rather than baseflow from water table aquifers.

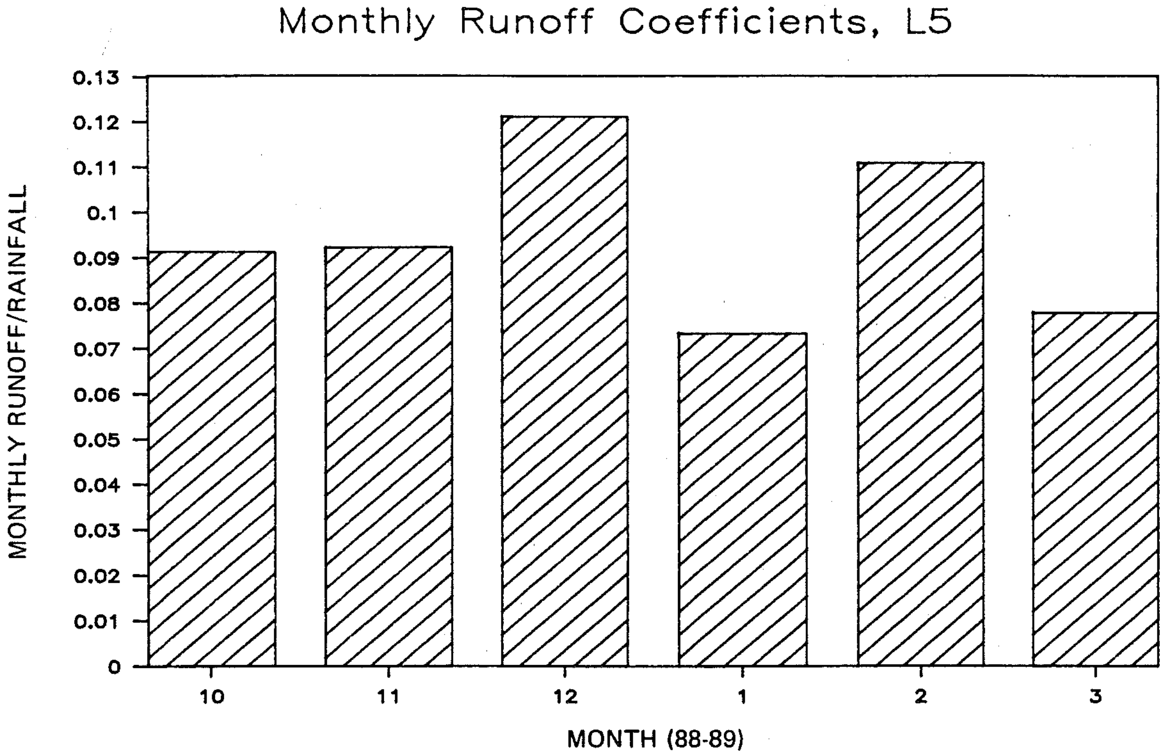
5.2.3.2 Land Use Station Hydrology. Land use stations ranged from industrial to open sites. Table 5-5 summarizes runoff volumes and coefficients for storms sampled at these stations. The control section for station L7 was altered in November 1988 by a debris dam; consequently, the rating curve for this station is no longer valid and runoff volumes could not be computed for Table 5-5. Runoff coefficients were highest at the industrial sites (L1 and L2), ranging from 0.42 to 1.00. In commercial and residential areas, runoff coefficients ranged from 0.02 to 0.31, with the highest values occurring at the high-density residential station (L6) and the lowest at a low-density residential station (L4). On the open station (L8), no significant runoff was measured from the relatively small storms occurring during the sampling period.

The seasonality of runoff at these sites is illustrated by the plots on Figure 5-17. The upper plot shows monthly runoff coefficients for station L5, a mixed residential area on the valley floor. At this station there is little seasonality in runoff coefficients, indicating that most of the runoff in urban areas on the valley floor is derived from impervious areas. In contrast, the lower plot for L4 shows a definite increase in monthly runoff coefficients as the season progresses. Thus, in low-density hillside residential and open areas, a significant portion of runoff is from pervious areas where antecedent soil moisture conditions are important.

Table 5-5. RUNOFF CHARACTERISTICS FOR EVENTS SAMPLED AT LAND USE STATIONS

Station	Land Use	Event	Runoff Volume (inches)	Runoff Coefficient (runoff/rainfall)	Rain Gage
L1	Industrial	1	1.3	**	San Jose NWS
		2	.28	.42	
		4	.25	.74	
		5	.39	.75	
		6	.19	**	
L2	Industrial	1	.59	.88	San Jose NWS
		2	.43	.64	
		5	.55	1.00	
		6	.15	**	
L3	Commercial	1	.05	.17	SCVWD 121
		2	.04	.08	
		4	.05	.17	
		5	.12	.17	
		6	.06	.15	
		7	.04	.20	
L4	Low-density	4	.01	.03	SCVWD 53
	Residential	5	.02	.05	
	(Hillside)	6	.02	.07	
		7	.005	.02	
L5	Residential	1	.02	.10	SCVWD 48
	(Valley)	2	.05	.13	
		3	.01	.05	
		4	.02	.05	
		5	.08	.16	
		6	.04	.13	
		7	.01	.05	
L6	Residential	1	.21	.31	San Jose NWS
	(Valley)	2	.10	.15	
		4	.05	.15	
		5	.11	.21	
		6	.03	.27	
		7	.06	.27	

** Runoff coefficient >>1 indicating either that rainfall information is not representative or that measured flow is not all storm runoff.



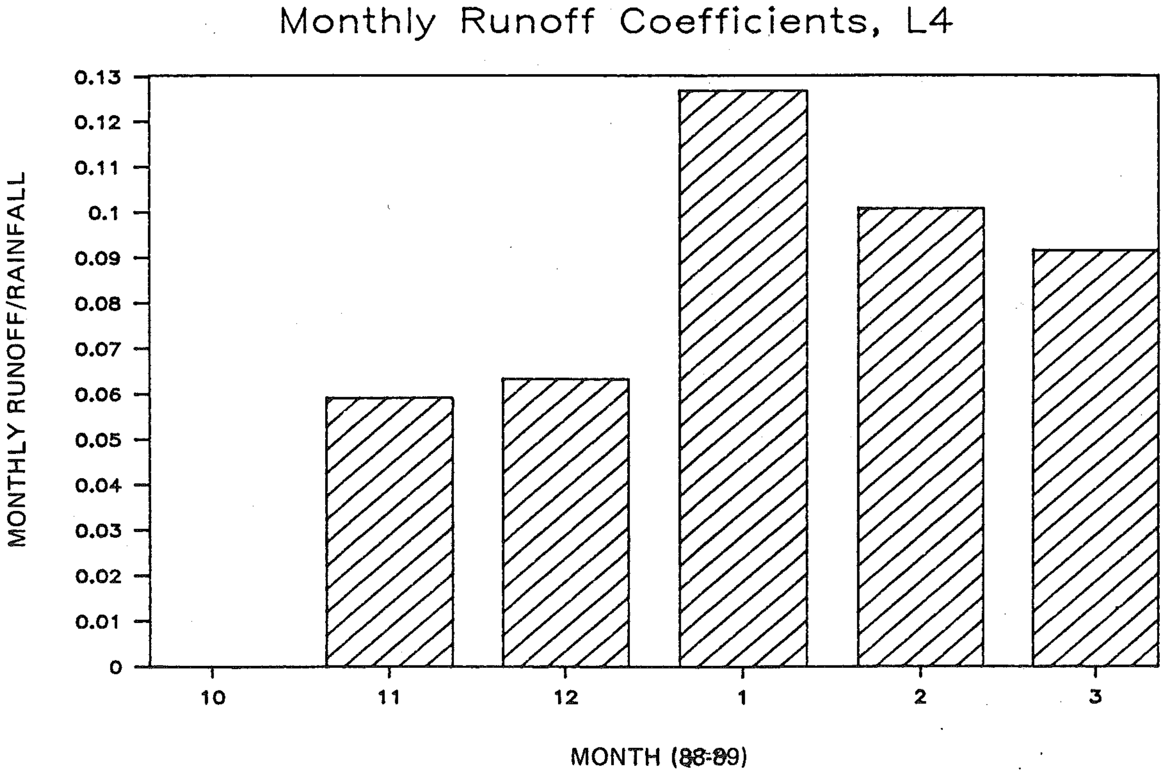


Figure 5-17. MONTHLY RUNOFF COEFFICIENTS AT VALLEY FLOOR (L5) AND HILLSIDE RESIDENTIAL (L4) SITES

5.3 RAINFALL-RUNOFF MODELING

The measured hydrologic data presented in previous sections provide insight into the historical magnitude and variability of rainfall and runoff in the Santa Clara Valley. However, the estimation of nonpoint source loads requires knowledge of the sources of storm runoff. Runoff from undeveloped areas will certainly differ in terms of water quality from runoff from urban areas on the valley floor, and little can be learned about the apportionment of runoff between developed and undeveloped areas through analysis of downstream streamflow records alone. The only way to estimate runoff from individual land uses and from ungaged areas, short of installing more stream gages, is by using a rainfall-runoff model. Rainfall-runoff models use physical and land use information about a catchment to calculate storm runoff from a given rainfall record. Rainfall-runoff models vary in complexity from relatively simple models such as the Rational Method (Linsley et al. 1982), to models which attempt to represent in detail the physical mechanisms through which rainfall is converted to runoff.

In this study, the Stormwater Management Model Version 4 (Huber and Dickinson 1988) was used to estimate runoff volumes from land use areas for loads calculations. This model, referred to as SWMM, contains a detailed mathematical description of the hydrologic cycle, including runoff from impervious and pervious areas; infiltration; percolation to the water table; groundwater flow into channels; losses due to evapotranspiration, interception, and depression storage; and routing of runoff down stream channels. The model also has water quality and treatment components which are useful in evaluating the effects of control measures. Thus, SWMM is sufficiently detailed and general in scope to model the processes which are relevant to the estimation of nonpoint source loads in the Santa Clara Valley.

The following sections summarize the application of SWMM to the Santa Clara Valley. Section 5.3.1 describes how the model was set up, including the discretization of watersheds and the estimation of model input parameters. Section 5.3.2 describes the calibration and verification of the model against measured streamflow data, and Section 5.3.3 briefly discusses the use of the model to estimate runoff volumes. A detailed description of SWMM modeling is provided in Appendix B.

5.3.1 Model Setup

The goal of this study was to estimate total nonpoint source loads from the Santa Clara Valley. Thus, SWMM was used to model runoff from the entire valley. For data management and calibration purposes, the valley was subdivided into the 11 major watersheds shown in Figure 2-4. Streamflow data for calibration were available at the downstream ends of 7 of these catchments; runoff from the remaining watersheds was estimated using SWMM without calibration (Table 5-6).

SWMM represents a watershed as a set of hydrologic units referred to as subcatchments. Each subcatchment is assumed to have a unique set of runoff properties, including rainfall, area, width, slope, infiltration characteristics, and percent of impervious area. For this study, each watershed was divided into subcatchments based on the variability of rainfall. Thus, a subcatchment was identified for each rain gage in a given watershed. To represent the variability of model parameters by land use, each rain gage subcatchment was further subdivided into subcatchments representing each land use. Up to six land use categories were used (open, low-density residential, medium-density residential, high-density residential, commercial, and industrial).

Rain data for the model were from the continuous recording gages described in Section 5.1. The model was run on a 15-minute time-step to model runoff response to the 15-minute rainfall records. Rain gage records were adjusted for orographic effects by first estimating the average annual rainfall for a subcatchment. The rain gage record was then multiplied by the ratio of this average subcatchment rainfall to the average annual precipitation for the rain gage.

Table 5-6. MAJOR WATERSHEDS FOR SWMM MODELING

Watersheds	Downstream Flow Data for Calibration?
Coyote Creek	Yes
Guadalupe River	Yes
San Tomas Aquinas Creek	Yes
Saratoga Creek	Yes
Calabazas Creek	Yes
Sunnyvale East Channel	Yes
Sunnyvale West Channel	No
Stevens Creek	Yes
Permanente Creek	No
Adobe-Matadero-Barron Creeks	No
San Francisquito Creek	No

SWMM also requires a number of physical parameters for each subcatchment. Area, slopes, and land use breakdowns were derived from data provided by the SCVWD. Percent impervious values for each land use were initially estimated from values reported in the literature and later adjusted based on calibration results for small storms on well-defined urban catchments. Soil infiltration parameters were estimated from Soil Conservation Service (SCS) surveys (SCS 1941, 1968). Other parameter values were estimated from tables in the SWMM users manual (Huber and Dickinson 1988). Many of these values were later adjusted during calibration of the model against measured streamflows.

As discussed in Section 5.2.2, storm runoff in the Santa Clara Valley is strongly influenced by seasonal changes in soil moisture. Soil moisture levels in the later part of the wet season tend to be higher at the start of storms due to infiltrated water from previous storms. This results in less infiltration and more runoff in the later portion of the season than in the early season. Because initial calibration indicated that SWMM did not adequately reproduce this effect, the SWMM infiltration algorithms were modified to allow for two new model input parameters for calibration. The first parameter, referred to as a soil depletion factor, is defined as a fraction of potential evapotranspiration and governs the rate at which the upper soil layer dries out between storms. The second parameter is the thickness of the upper soil layer. This parameter determines the storage capacity of the upper soil layer. These parameters were adjusted during calibration until the observed seasonal runoff pattern was reproduced by the model.

As previously discussed in Section 5.2.3, hydrographs for many streams in the area show a 2- to 3-day recession following storms which cannot be explained by surface runoff processes alone. Since the water table in most of the valley is far below the streambeds, this recession was modeled as interflow rather than flow from water table aquifers. To accomplish this, the subsurface component of SWMM was set up as a linear reservoir at relatively shallow depth (10-15 feet below the ground surface). This subsurface interflow model was calibrated such that the subsurface storage zone filled up quickly through infiltration during storms and discharged rapidly following the recession of the surface runoff hydrograph.

5.3.2 Calibration and Verification

Although SWMM is a state-of-the-art model of rainfall-runoff processes, it represents an idealization of the actual processes occurring in a catchment. In addition, the spatial variability of model input parameters is difficult to account for in large catchments with many types of geology and land uses. Therefore, the model usually must be calibrated against measured streamflow data to produce accurate results. The calibration consists of running the model, comparing model prediction to measured streamflows, and adjusting the model input parameters to better match the observed flows. The process is repeated until the comparison between measured and predicted flows in deemed adequate. Calibration is then followed by verification, in which the calibrated model is run and compared to streamflow records for a period not included in the calibration period.

Calibration and verification periods were limited to the period 1974 to 1989 by the availability of concurrent streamflow and rainfall data. Calibration and verification periods were selected to reflect the annual variability of rainfall and runoff conditions, and generally contained a mix of wet, dry, and average years. Because of occasional gaps in streamflow data, calibration periods varied slightly from watershed to watershed, but generally ranged from 5 to 9 years in length. Independent verification periods ranged from 3 to 6 years in length.

Calibration was accomplished by adjusting the appropriate SWMM input parameters to match predicted hydrographs. For adjusting total wet-season runoff volumes, the important parameters were the percentage of impervious area in urban areas and the saturated hydraulic conductivity for infiltration in open areas. Other important parameters included infiltration and soil moisture storage parameters, depression storages, and groundwater flow coefficients.

Because the focus of this modeling effort was to estimate annual loads, the primary goal of calibration was to match measured wet-season runoff volumes. Daily volumes were used to give insight into how well the model was simulating individual storm volumes, and monthly volumes were used to ensure that the model was reproducing observed seasonal runoff patterns. The quality of calibration was quantified by the root mean square error (RMSE) and bias of predicted versus measured wet-season volumes, expressed as percentages of the mean annual flow:

$$\text{RMSE} = 100 \left(\frac{\sum^{n} (X_p - X_m)^2}{N\overline{X}_m} \right)^{\frac{1}{2}} \quad (5\text{-}1)$$

$$\text{BIAS} = 100 \sum^{n} (X_p - X_m) \,/\, \overline{X}_m \quad (5\text{-}2)$$

where X_p = predicted wet-season volume (in.)
X_m = measured wet-season volume (in.)
N = number of years
$\overline{X}_m$ = measured mean wet season volume (in.)

In addition, a Kolmogorov-Smirnov Hypothesis test (95 percent confidence level) was used to check that predicted daily flows accurately represented the frequency distribution of measured flows.

Details on the model calibration and results are provided in Appendix B. The effects of calibration errors on the uncertainty in loads estimates are addressed in Appendix H. Table 5-7 summarizes the RMSE and BIAS for model calibration of the eight watersheds with measured streamflow data. RMSEs in annual flow predictions for Calabazas Creek, Sunnyvale East Channel, Saratoga Creek, and San Tomas Aquinas Creek were all on the order of 10 to 25 percent. These calibrations were also unbiased, with overall biases generally on the order of 1 or 2 percent. This level of accuracy is

Table 5-7. SUMMARY OF SWMM CALIBRATION/VERIFICATION

			Calibration			Verification			Combined Calibration and Verification Period		
Watershed	Calibration Period	Verification Period	Mean Wet-Season Runoff (in.)	RMSE (%)	Bias (%)	Mean Wet-Season Runoff (in.)	RMSE (%)	Bias (%)	Mean Wet-Season Runoff (in.)	RMSE[a] (%)	Bias[b] (%)
Calabazas Creek	1976-80, 86-88	1980-83, 1984-85, 1988-1989	4.08	8	-5	5.51	13	6	4.73	11	1
Stevens Creek	1977-1981	1975-77, 1981-83	1.96	15	1	2.15	45	1	2.06	34	1
Sunnyvale East	1974-1982	1984-1989	5.66	6	3	3.31	3	-9	4.59	9	-1
Saratoga Creek	1974-1982	1982-1986	6.57	30	-8	11.98	13	10	8.19	22	0.1
San Tomas Aquinas Creek	1975-1981	1983-1987	6.58	17	-7	6.93	25	5	6.73	21	-2
Coyote Creek	1988-1989	None	0.73	1	-1	None	None	None	0.73	1	-1
Berryessa Creek	1974-1979	1980-1982	1.39	19	-12	4.69	25	16	2.49	29	6
Guadalupe River	1977-1981	1981-82, 1987-89	2.92	38	-2	1.73	40	-3	2.4	40	-2
STUDY AREA			2.80	25	-4	2.98	22	5	2.8	25	-1

[a] RMSE measures the average error in predicted wet-season runoff, as a percentage of the mean wet-season runoff volume.

[b] BIAS measures the average bias (tendency to under- or over-predict) in predicted wet-season runoff, as a percentage of the mean wet-season runoff volume.

consistent with results obtained in other studies (Alley 1986). The model was less accurate in predicting runoff from Stevens Creek, with an RMSE of 34 percent for the combined calibration-verification period.

The model was able to predict the 1988-89 runoff volume at the downstream Coyote Creek streamgage within 1 percent. However, only 1 year of data were available at this streamgage, and the ability of the model to predict Coyote Creek flows in other years is as yet unverified. In particular, we have little data on how this watershed behaves in very wet years. In calibrating the model for this watershed, the model input parameters were consistent with those used in other watersheds. It would therefore be reasonable to assume that a comparable (10 to 25 percent) level of accuracy would be obtained in simulating multiple years of runoff.

Significant calibration difficulties were encountered on the Guadalupe River, primarily due to uncertainty with regard to measured flows. Flow in the Guadalupe River during a storm has the following components: (1) stormwater runoff from areas below reservoirs, (2) reservoir releases and spills, and (3) flow from permitted point-source dischargers. In addition, there are numerous flow diversions to groundwater recharge facilities. These flow diversions are assumed to be small during winter storm periods, but there is still considerable uncertainty in the magnitude of these diversions at any point in time.

Because the goal of the SWMM calibration was to predict stormwater runoff, the model was calibrated to the stormwater component of the total Guadalupe flow. This component was estimated by subtraction of measured reservoir releases from the measured total flow:

$$Q_{sw} = (Q_{tot} - Q_{res}) \tag{5-3}$$

where:

Q_{sw} = estimated daily average stormwater runoff (cfs)
Q_{tot} = measured total flow at the gage (cfs)
Q_{res} = measured reservoir releases (cfs)

This algorithm assumes that during storms, diversions and permitted discharges are small components of the total flow. The resulting estimated flows were found to be unrealistic in many cases. Runoff coefficients estimated for the basin using Q_{sw} were inordinately high, especially in late season storms. In several instances, runoff coefficients greater than 1.0 (indicating more runoff than observed rainfall) were computed. Possible sources of this error include:

(1) industrial wastewater and pump and treat discharges into the river,

(2) errors in the reservoir release data,

(3) errors in the measured total flows.

Our investigation of point source dischargers into Guadalupe River indicates that this source should not be a significant component of total storm flows. Therefore, the most likely source of error is in the measured reservoir releases and streamflows.

Given the uncertainty in the measured flows, calibration was performed for periods when the flow data appeared to be most reasonable (i.e., when runoff coefficients were reasonable). Estimated flow data were generally most reliable during dry years and early season storms when reservoir releases were small. Input parameters were also constrained to remain consistent with values used in other catchments. As a result, the model was able to predict annual runoff volumes with an RMSE of 40 percent and a BIAS of -2 percent.

5.3.3 Use of the Model to Calculate Land Use Runoff Volumes

Once the model was calibrated and verified, it was applied to each watershed to estimate runoff volumes from the various land uses. When estimating land use runoff volumes in areas that were calibrated against streamgage data, model results were corrected by a scaling factor to account for the calibration error for each year:

$$Q_{ij} = QP_{ij} * (Q_{pred}/Q_{meas})_j \tag{5-4}$$

where:

Q_{ij} = annual flow volume from land use i for year j (ac-ft)
QP_{ij} = SWMM-predicted annual flow from land use i for year j (ac-ft)
Q_{pred} = SWMM predictions at the streamgage for year j (ac-ft)
Q_{meas} = Measure annual flow volume at the streamgage for year j (ac-ft)

This correction factor ensures that the total estimated flow equals the measured flow at the streamgage. As a result, in these basins the model was used only to estimate the distribution of the total flow among the various land uses. In uncalibrated areas, the model was applied using input parameters estimated from the calibration results for adjacent similar watersheds.

SECTION 6

6.0
WATER QUALITY

This chapter summarizes the analysis and interpretation of water quality and sediment data obtained from the monitoring program conducted during this study, and compares the results obtained with findings from the earlier relevant studies which were discussed in Section 3.0.

6.1 WATER QUALITY BACKGROUND

The predominant water quality focus in San Francisco Bay has changed with time, in response to the availability of information and progress made in the control of pollutant discharges.

Between 1962 and 1970, comprehensive studies of San Francisco Bay were conducted by the University of California's Sanitary Engineering Research Laboratory (SERL). These studies provided the first documentation of water quality problems in the Lower South Bay. Water quality issues identified in the SERL report were attributed primarily to discharges of poorly treated domestic wastewater to Lower South Bay receiving waters. The increasing organic loads in this region of the Bay was causing extreme depressions in dissolved-oxygen levels. In addition, levels of ammonia in the receiving waters were exerting unacceptable levels of toxicity.

Since the SERL studies, all wastewater treatment plants in the Lower South Bay have installed tertiary treatment. These improvements included both significantly greater removal of organic material and nitrification to eliminate the toxicity problems associated with ammonia, as well as further reducing mass emissions of Ultimate Oxygen Demand (UOD). As a direct result of these improvements, dissolved-oxygen levels in Lower South Bay have increased significantly and are no longer considered to be limited by point source discharges. Concerns have shifted away from issues of organic loading to potential impacts of toxic trace metals

Poor water circulation in Lower South Bay is considered to limit the capacity of this region to accept discharges of toxic trace metals. Much concern exists regarding potential accumulation of these pollutants in both sediments and animal tissues and the possible chronic impacts on biological communities in the Lower South Bay. As a result, the Regional Board has initiated a process designed to determine the assimilative capacity of critical receiving-water segments of the Bay.

Most concern regarding water quality in Lower South Bay has been directed towards trace metals. Increasing levels of certain trace metals have been documented in both water and sediments along transects from Central Bay to Lower South Bay. Although organic contaminants may be as much a concern, the comprehensive studies necessary to assess the distribution of organic contaminants in the Bay have not been conducted.

A 5-year study (1981-1986) of Lower South Bay documented substantial fluctuations in levels of trace metals in the receiving waters (Stevenson et al. 1987). The study documented no deleterious impacts of elevated levels of metals on biota, however, a prolonged period of elevated levels of trace metals was found to roughly correspond with increased occurrences of a necrotic shell condition in shrimp collected in this region. Although cause-and-effect relationships could not be established, the concurrence of these two events led to some concern for possible chronic toxicity. USGS studies of intertidal benthic communities (Nichols et al. 1986) near a point source discharge documented population declines corresponding to increases in trace metal concentrations in the sediments. In both studies, cause-and-effect relationships could not be established due to variation in a number of other potential causal factors. Nevertheless, these studies have focused attention on possible impacts of excessive accumulations of trace metals in this region.

Trace metals of primary concern in Lower South Bay are mercury, selenium, silver, copper, and nickel (KLI/LWA 1987; Phillips 1988). The primary source of mercury in Lower South Bay is believed to be due to natural deposits of cinnabar in the Lower South Bay watershed. Sources of selenium in Lower South Bay have not been clearly established. Point source dischargers and water imported from the San Luis Reservoir for groundwater recharge purposes have been suggested as potential sources. Silver in Lower South Bay is believed to be due primarily to point source dischargers. Levels of copper and nickel in Lower South Bay are thought to result from both point source and nonpoint source discharges. These two metals were the only ones that were found to exceed EPA saltwater criteria on a regular basis. In addition, nickel was one of the only trace metals measured in sediments during the 5-year SBDA study that exhibited both strong temporal and spatial trends.

The limited information regarding pollution by conservative organic compounds in Lower South Bay indicates that organic pollutants are introduced more sporadically. Episodic increases in chlorinated hydrocarbons have been identified throughout the Bay. Periodic elevations in tissue burdens have been documented in shrimp, fish, and molluscs.

The relative contribution of metals and organic pollutants due to point and nonpoint sources has only been crudely estimated in the past. Increases in trace metals in Lower South Bay receiving waters during the 5-year SBDA study did not correlate with mass emissions from the point source dischargers. As a result, it was suggested that increases may have resulted from either nonpoint dischargers or factors affecting the equilibrium between metal concentrations in sediments and water. This study was designed to provide the first quantitative data regarding mass emissions of toxic pollutants associated with nonpoint source discharges.

Mass emission data derived from this study will be used to estimate total mass emissions of toxic pollutants to San Francisco Bay and provide more reliable estimates of the relative contribution of pollutants from point and nonpoint sources. Ultimately, these and other data will be used by the Regional Board to assist in developing a waste load allocation for Lower South Bay.

A data base on water quality in the upstream, freshwater reaches of the Guadalupe River and Coyote Creek was developed by a USGS-SCVWD program that monitored eight stations between the years 1979 and 1986. Stream water quality data were secured on between about 30 to 60 occasions during this period at each of the stations. Conventional pollutants and major ions were analyzed, with a significant emphasis on nitrogen and phosphorus forms. Metals and a set of organic pollutants were measured in between about 7 and 15 samples at each station. These data have been tabulated in Appendix F, and summaries of the data stratified by month and by wet or dry season are listed.

The present study does not emphasize nutrients, since dissolved oxygen and eutrophication issues are no longer a significant concern in the bay. The metals data are relevant, but their utility is constrained by the fact that the USGS-SCVWD data base focussed only on soluble metals in the water column (which were consistently quite low). Metals concentrations in sediments, however, were used in comparisons to this study. Typical ranges for dissolved metals at all the stations, which are mostly upstream of major urban runoff inflows, are tabulated below for reference.

Zinc	10-30 μg/L	Cadmium	generally ND
Lead	2-4 μg/L	Chromium	generally ND
Copper	2-3 μg/L	Mercury	generally ND
Arsenic	1-2 μg/L	Nickel	generally ND

Of the organic pollutants monitored, all were consistently less than detectable limits, except for total diazinon and total 2,4-D. These were consistently observed at most of the stations at concentrations of 0.02 to 0.05 μg/L.

6.2 DATA ANALYSIS PROCEDURES

During this study, water quality and flow measurements were made at the monitoring locations shown on the location map presented earlier as Figure 4-1. A total of six or seven grab samples were taken during dry weather at the four stream stations, and one grab sample at each of six reservoir discharge locations. Composite samples for five to seven different storm events were obtained at each of the four stream stations and at seven land use stations. Samples were analyzed for conventional pollutants (such as suspended solids, BOD, hardness, and nutrients), bacteria, trace metals, TOC, and synthetic organics. Data obtained by the monitoring conducted under this study are summarized in Appendix D. Reduced forms of these data are presented, compared, and discussed in this section.

The principal focus of the analyses that were applied to the data was to interpret results in a way that would apply to the development and testing of a procedure for estimating the mass loading of pollutants to Lower South Bay. A supplementary objective was to assess the effects of nonpoint source runoff on the water and sediment quality of the tributary streams. The discussions that are presented below emphasize the organic and inorganic toxic pollutants measured in the stormwater runoff and stream samples.

Monitoring results are generally reported as event mean concentrations (EMCs), i.e., the average concentration in the volume of runoff or streamflow resulting from a particular storm event. Previous studies have found EMCs to be highly variable and following a lognormal distribution. Following experience gained in other studies dealing with storm runoff, we tested the distributional form of the variable EMCs at each study site and concluded that the Santa Clara data can also be represented by a lognormal distribution. This permits the variable runoff quality characteristics for different sites to be compared, by comparing the site median concentrations (SMCs) of a particular pollutant from a group of sites. For a lognormally distributed set of EMCs, the best measure of central tendency is the mean of the log-transformed values (the log mean). This corresponds in arithmetic space to the median concentration, hence the use of the SMC to examine similarities or differences between sites.

The basic analysis/evaluation procedure that was applied for most pollutants is illustrated by Figures 6-1a and 6-1b for the case of total suspended solids (TSS). Those for which most or all of the samples yielded concentrations below the detection limit could not be analyzed this way, and are discussed in narrative format in the appropriate subsection of this section.

Figure 6-1a shows the probability distribution of the EMCs measured in the monitored storms at the four sites (L3, L4, L5, and L6) with residential/commercial land uses. Site L1, an industrial park, is also included because its characteristics would be expected to most closely fit the general characteristics of this grouping. In Figure 6-1b, the two plots show the same results for the remaining two land use sites: L2, which is designated heavy industry, and L7, which is undeveloped open land.

Confidence in the statistical characteristics of a variable data set, particularly the estimate of the SMC, is influenced significantly by the number of observations. In this case, even with the very sparse data set consisting of only three to six observations at a particular site, the lognormal pattern is strongly supported, and the coefficients of variation are relatively small, so that estimates of the SMC for each site are appreciably better than could have otherwise been the case. These data can be examined by means of box plots to illustrate graphically the comparison

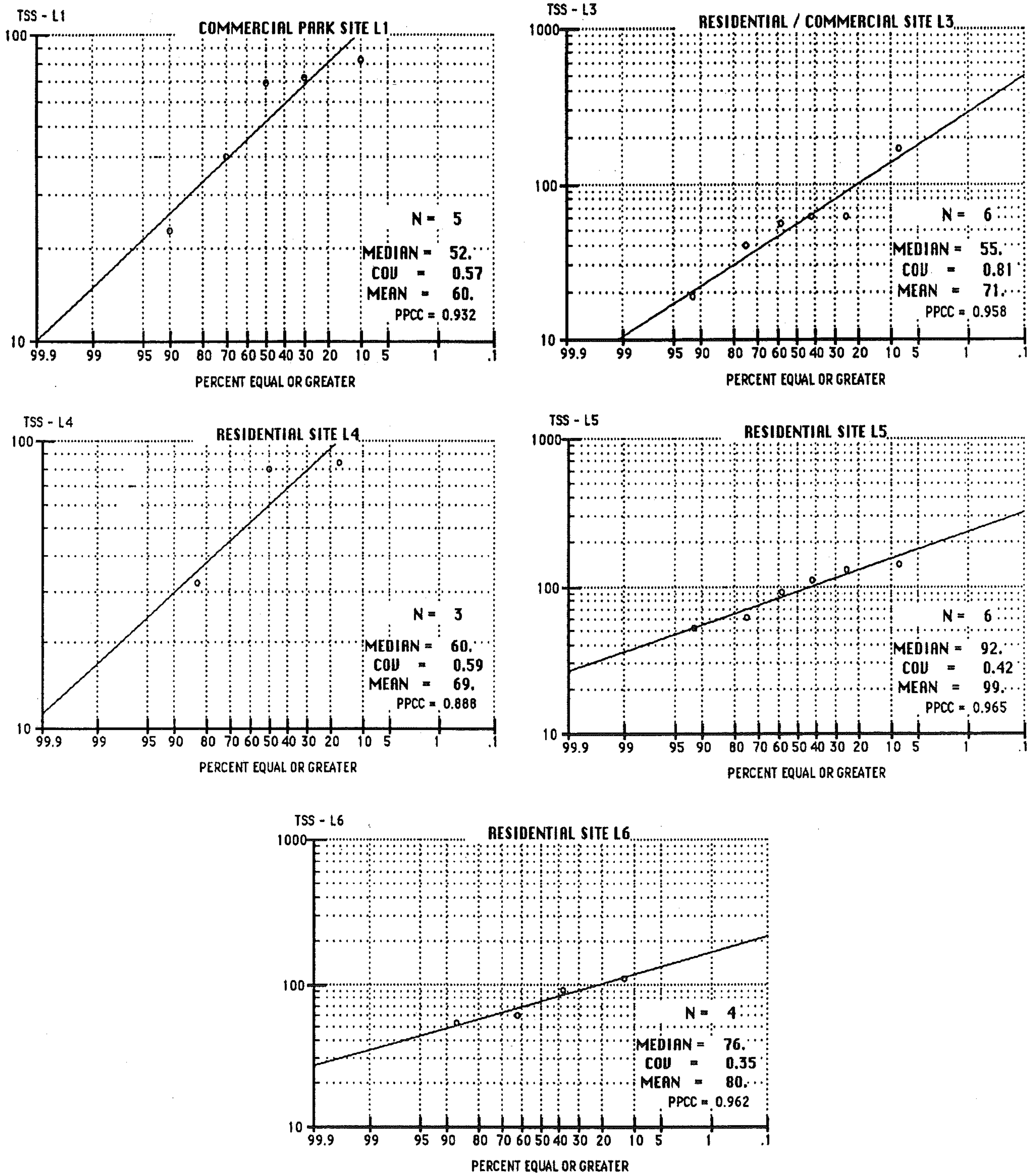
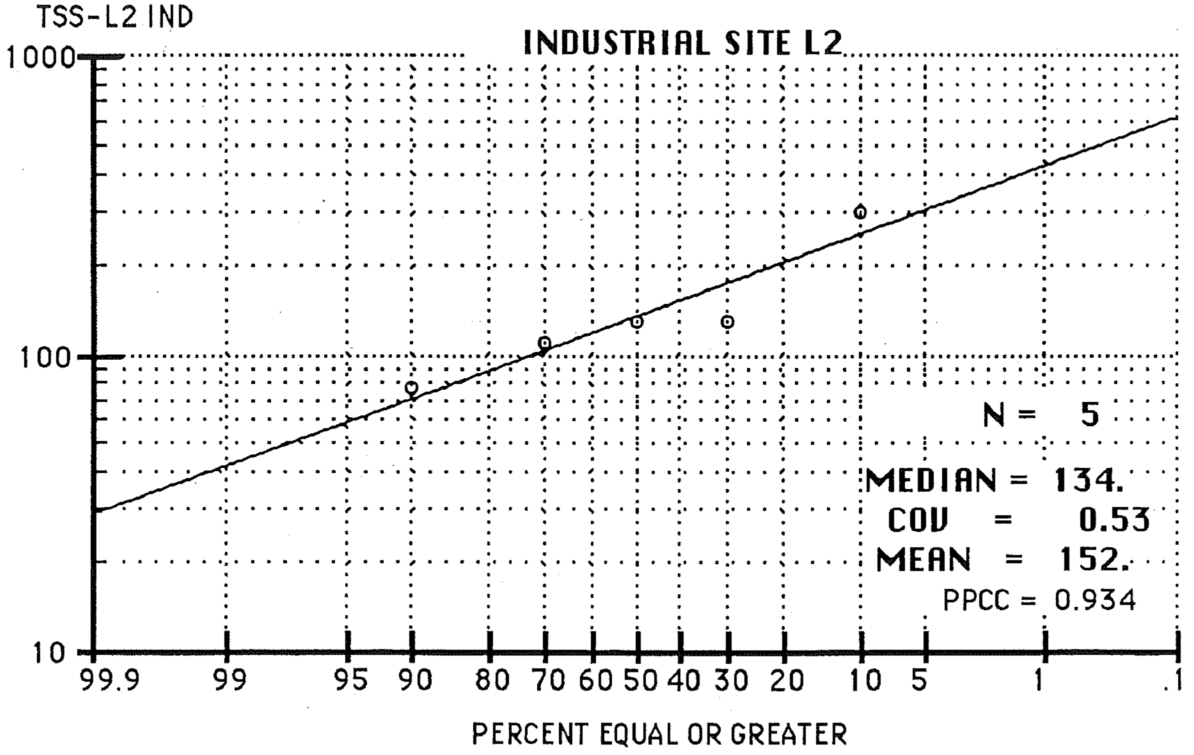


Figure 6-1(a). TSS Concentrations in Monitored Storm Events at Residential/Commercial Land Use Sites



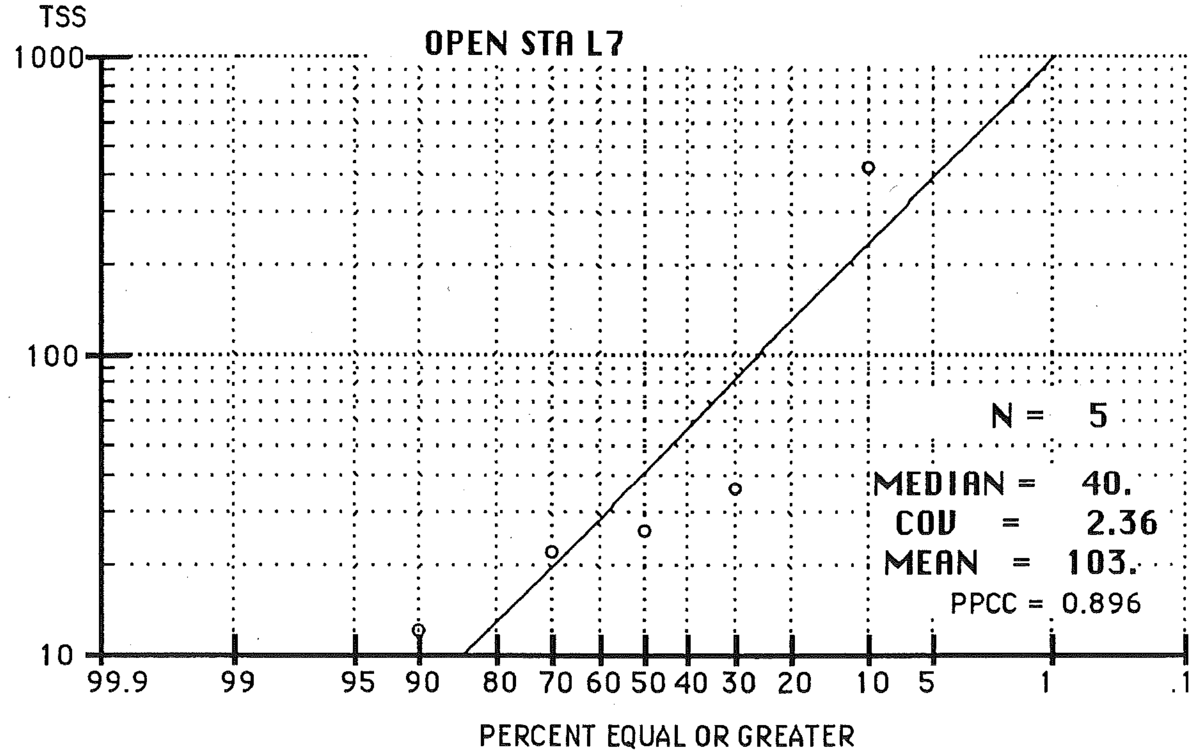


Figure 6-1(b). TSS Concentrations in Measured Storm Events at Industrial and Open Land Use Sites.

between sites, as shown by Figure 6-2. The 90 percent confidence interval in the value of the median (transform of the log mean) shown is computed using Student's t-test. These results indicate that the differences in the SMCs for the residential/commercial sites (L1, L3, L4, L5, and L6) are not statistically significant, and suggest the idea that the EMCs from all these sites may be pooled to provide an estimate of the overall SMC for all residential/commercial land uses in the watershed. This result is shown by the distribution of pooled EMC values presented in Figure 6-3a. For comparison, the probability distribution of the separate SMCs for the five sites is shown by Figure 6-3b. In the illustrated case (for TSS) both approaches give essentially the same estimate for the SMC of residential/commercial land uses in the watershed. The same analysis applied to other pollutants produced comparable relationships, though in some cases the match between the two approaches was not quite as close.

For the purpose of load estimation, we elected to utilize the pooled EMCs to estimate the characteristics of the variable runoff quality from these land use types. The larger sample size improved confidence in the estimate of the overall SMC, and this approach eliminated potential bias resulting from the assignment of equal weight to all monitoring sites, regardless of the number of events monitored. Further, the assumption that the pooled data can be considered to represent random samples from a general land use type also provides information on the magnitude of the expected event-to-event variability in EMCs. Comparisons between sites are properly based on the median (SMC), but for mass loading estimates the appropriate statistic to use is the mean. The concentration value for the mean storm runoff event is readily computed from the median and coefficient of variation for a lognormal distribution:

$$\text{mean} = \text{median} \times \sqrt{(1 + \text{COV}^2)} \qquad (6\text{-}1)$$

Use of the mean in load calculations properly accounts for the fact that a large event will account for more total mass than many small ones.

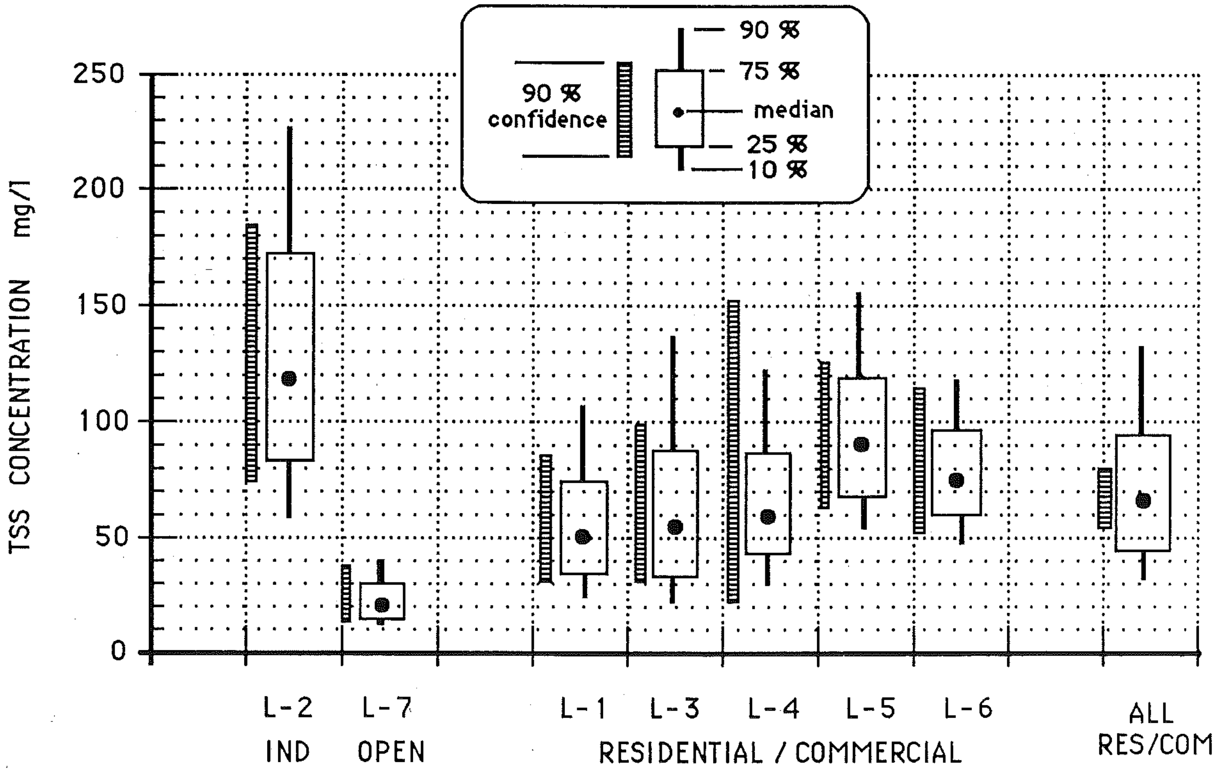


Figure 6-2. Box Plot Comparison of TSS Concentrations from Land Use Sites

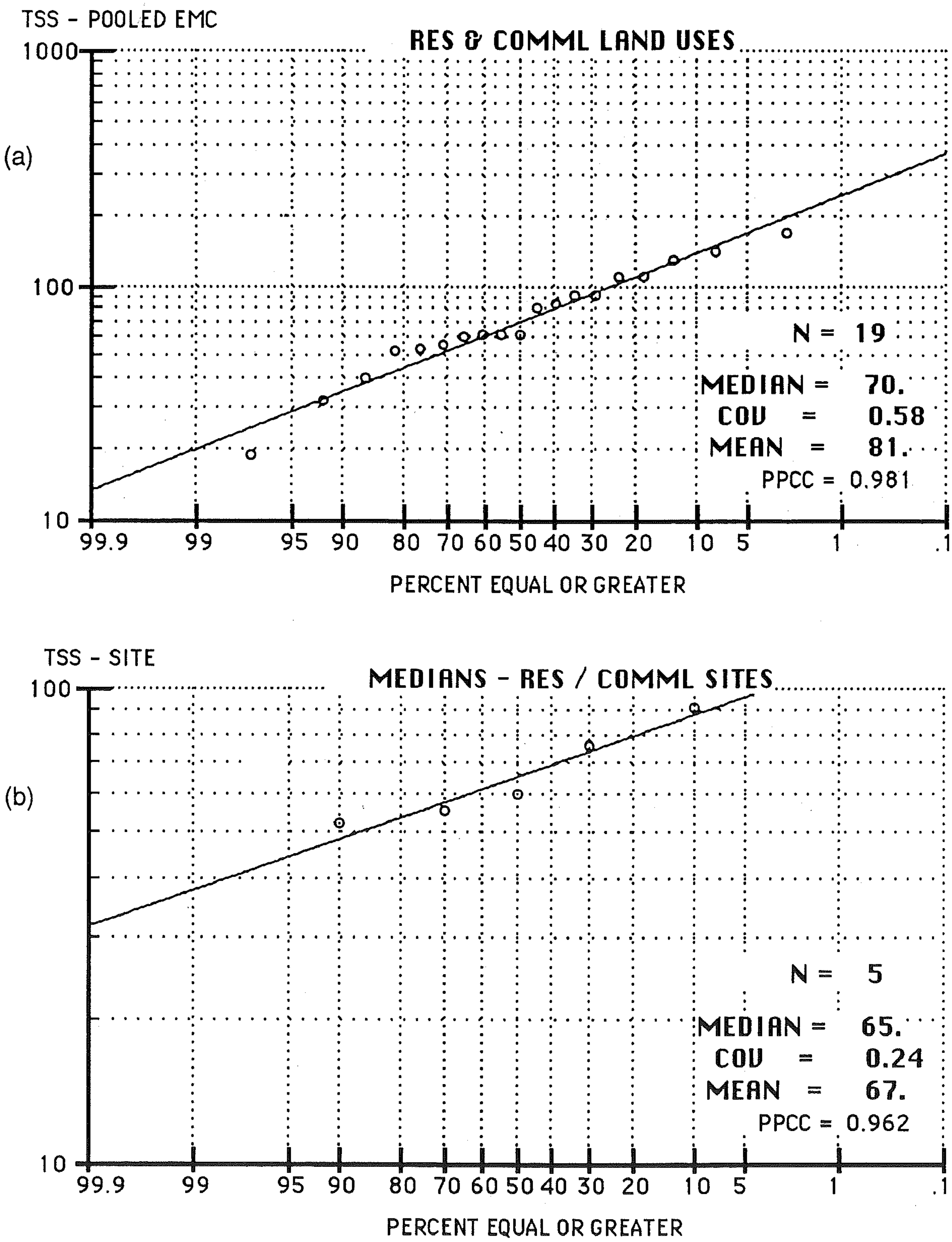


Figure 6-3. Runoff Quality Characteristics for Residential / Commercial Land Use Sites

6.2.1 Outliers

As an inspection of the listing of all of the individual event mean concentrations (EMCs) presented in Appendix D suggests, and as the probability plots indicate more clearly, a small number of the measured pollutant concentrations appear to be "outliers." These are values that are either appreciably higher or lower than the bulk of the other values in the associated data set.

We examined each piece of data to determine that the non-typical value was not the result of recording error, nor attributable to sampling error or problems with laboratory QA/QC. For those that remained after this check, we considered the possiblility that these values should be treated as "outliers," and excluded from use in determining statistical characteristics which would be used in developing load estimates. A high outlier in a data set will result in an overestimation of the mean, but a larger number of the apparent outliers are low values, which have the opposite effect.

In most cases, we elected to retain the outlier values rather than discard them. An observation with a value appreciably different than others in its data set does not necessarily reflect a sampling or laboratory error. In a small sample, with a parameter known to be variable, it may simply represent the occurrence of a value of the indicated magnitude at a frequency of occurrence out of proportion to its actual frequency. Where the difference was not extreme, and where the sample statistics for the median would not be radically affected, we included such values in the analysis.

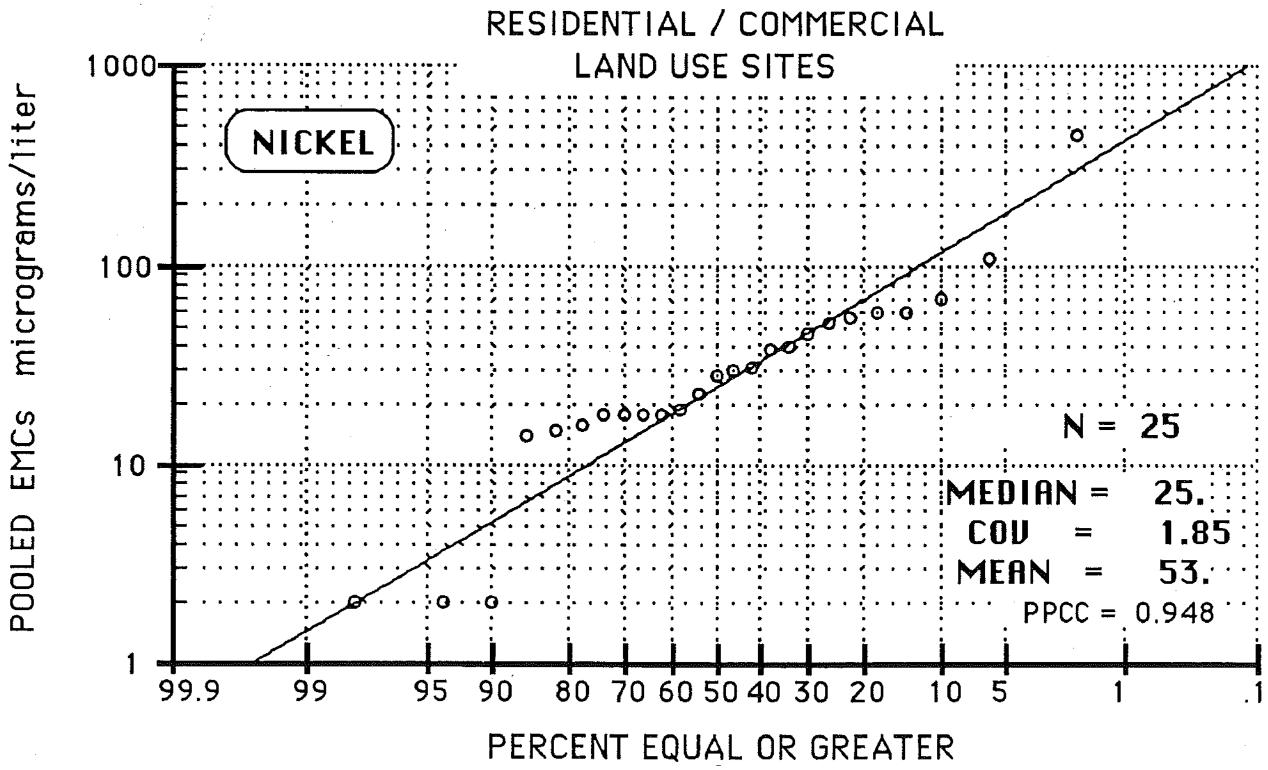
The effect on uncertainty that would result from further reducing an already small sample size was one of consideration in our decision. It was considered desirable to retain as many values as possible in the data set, because of questionable justification for removing them, and because we determined that with the data analysis approach that was adopted, the exclusion or inclusion of the values in question would not significantly effect the estimates of runoff loads.

The pertinent features of the analysis approach that miitigate the influence of outliers include the pooling of the small samples for individual residential/commercial land use sites, and the use of site median values as the basic statistic for characterizing the water quality data. The following example illustrates this aspect.

Figure 6-4 shows the probability distributions for copper and nickel concentrations in stormwater runoff from the residential/commercial land use category. For the copper data, the highest and lowest values (320 and 1 µg/L, respectively) deviate substantially from the pattern described by the other 23 observations. For nickel, there are three detection limit values at 2 µg/L, and one unusually high value at 450 µg/L.

We assume that these outliers are "true" values, but that they appear more frequently than they should in a sample of 25. Plotting them at their real probability (if it were known) would tend to move the high values to the right, and the low values to the left on the probability scale. Repeating the analysis with these outliers removed results in little change in the median value. The SMC for copper changes from 31 to 33 µg/L, and for nickel the change is from 25 to 31 µg/L. This illustrates the robust nature of the analysis approach using the probability distributional form to estimate site quality characteristics. The presence of outliers does not significantly distort estimates of the site median concentration. For this reason, our estimates for the SMCs include all of the measured data, including values that might be considered to be outliers.

Although the estimate of the median is not sensitive to outliers, this is not the case for the coefficient of variation (COV). The value assigned to the coefficient of variation which, together with the median, provides



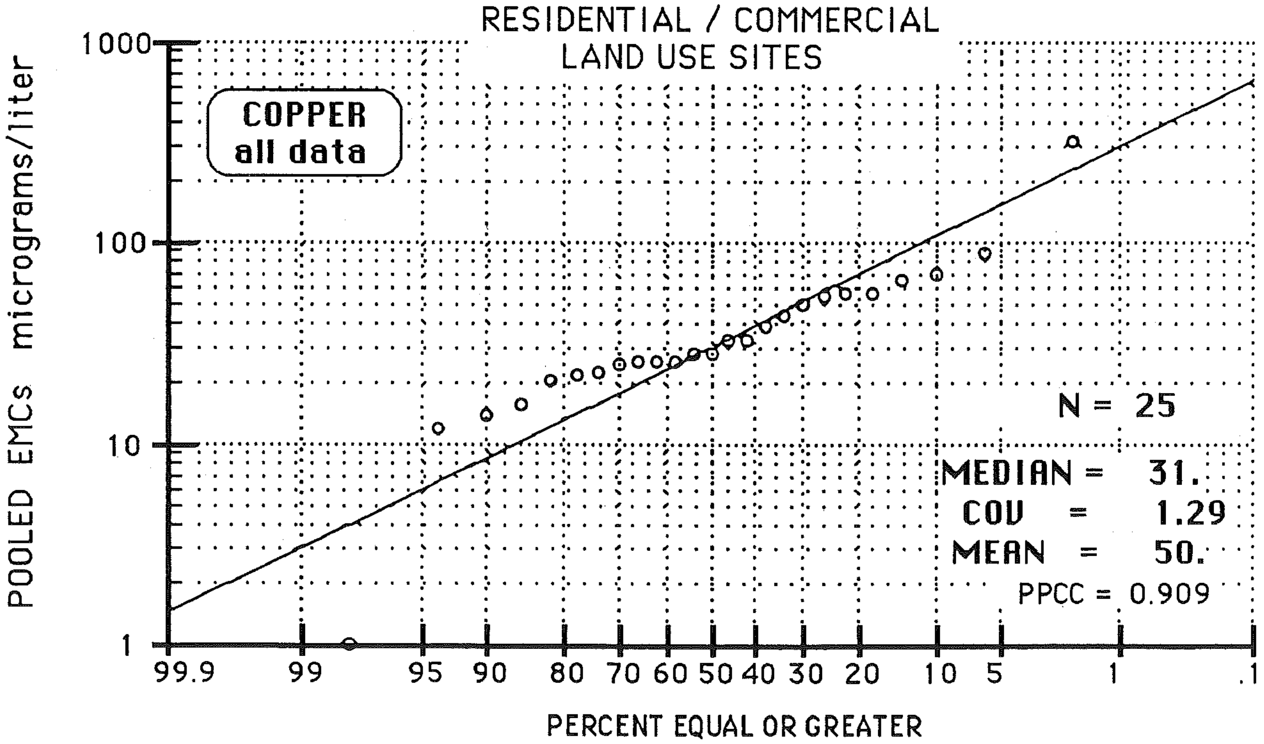


Figure 6-4. Nickel and Copper Concentrations in Measured Storm Events at Residential / Commercial Land Use Sites.

the estimate of the mean value (equation 6), has an important influence on mass load computation. For small samples, estimates of variance are much more uncertain than estimates of the median, even without the presence of outliers. The COV is reflected by the slope of the distribution line, and it can be seen (Figure 6-4) that the presence of outliers clearly distorts this estimate. A repeat of the illustrated analysis with the outliers removed reduces the COVs from 1.29 to 0.57 for copper, and from 1.85 to 0.66 for nickel.

The approach we adopted was essentially as follows. Except for obvious and extreme cases, suspected outliers were retained, displayed in results, and included in computations of site median values. Recognizing that small sample size and outliers make estimates of the coefficient of variation (COV) much more uncertain than estimates of median values, we applied judgement in assigning values for COV for use in the analysis, particularly for estimating mean values from which loads are computed. These estimates were guided in part by study data, and in part by literature and experience relating to data of this nature. Most of the monitoring data sets produced COVs in the range of about 0.5 to 1.0, and this range is consistent with results from much larger stormwater runoff data bases examined by the NURP and FHWA studies. For the data sets in this study that show very high or low COVs, we adjusted the assigned values so that they fall within bounds indicated by past experience. When a computed COV is less than 0.4, we assigned a value of 0.4 for subsequent use in computing the mean for loading estimates. Any COVs using all the data that were greater than 1.3, were assigned a value of 1.3.

6.2.2 Correlation of Runoff Volume with Trace Metals Concentrations

An extensive analysis of the correlation structure between storm size (runoff quantity) and EMC was performed. Because the analysis is unreliable for small sample sizes, the correlation analyses were performed using pooled data from all appropriate sites. The pooled data utilized for this correlation analysis include data from land use stations L1, L3, L5 and L6, and data from four stream stations, S1 to S4. Figures 6-5a and 6-5b present plots of the relationship between zinc concentrations and runoff volumes, which provides a typical illustration of the overall patterns observed. The square of the linear correlation coefficient (r) provides a measure of how much of the variation in concentration is attributable to storm size. In the cases shown, the correlation is not significantly different than zero.

Table 6-1 summarizes the results of this evaluation by listing the correlation coefficients obtained. The lack of correlation between water quality and storm volume indicated in this table suggests that the effect of storm volume on water quality (if any) cannot be distinguished given the numerous other factors affecting water quality and the limitations in the data set, which reflects essentially drought conditions and is biased towards smaller storm volumes. These results are consistent with findings from the NURP program on urban runoff and from a FHWA program on highway stormwater runoff, both of which had very large data bases available for analysis.

In the sections which follow, monitoring results are summarized in terms of the site mean or site median concentration of a pollutant for land use groupings that are based on the type of analysis described above.

Three different land use groupings have been selected (along with sample locations on four streams), for summarizing water quality results and for projecting loadings. These consolidated results are compared with runoff quality data from other sources in this section, and used with flow data to generate projections of pollutant loadings, as discussed later in Section 8.0.

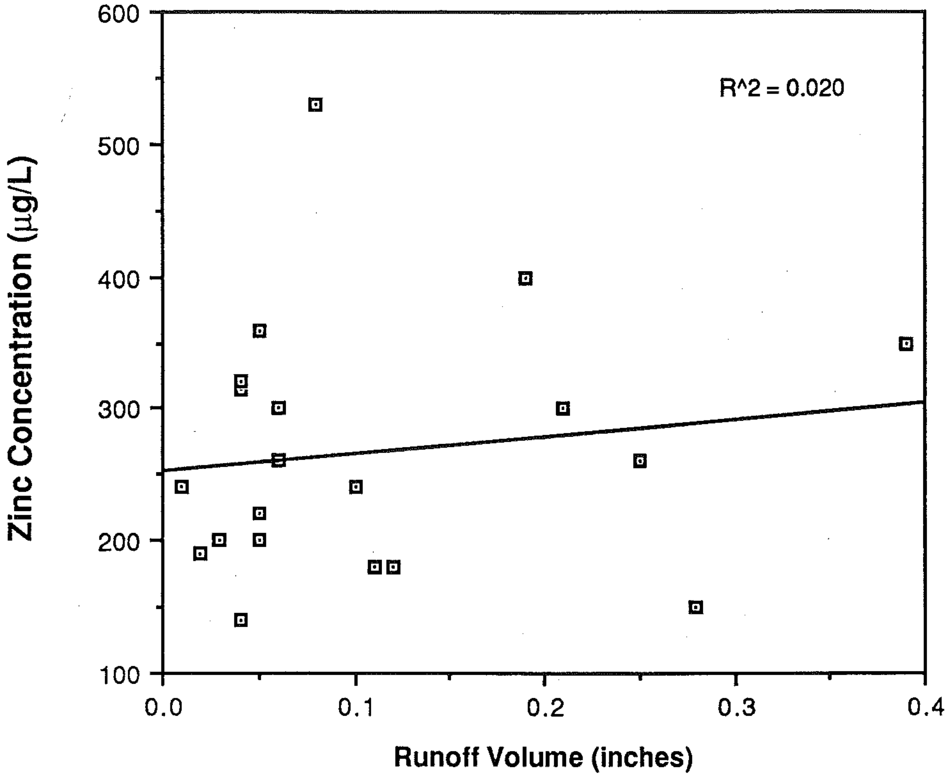


Figure 6-5a. Relationship Between Zinc Concentration
and Storm Runoff from Pooled Landuse Stations (L1,L3,L5,&L6)

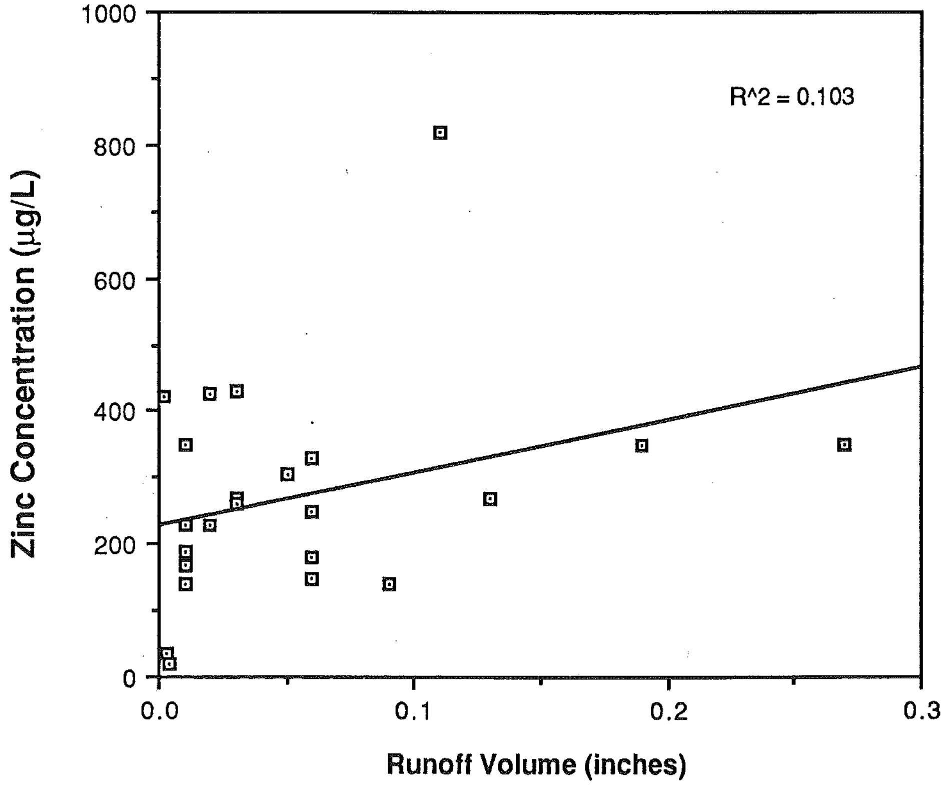


Figure 6-5b. Relationship Between Zinc Concentration
and Storm Runoff from Pooled Stream Stations (S1,S2,S3,&S4)

Table 6-1. Correlation Coefficients of Trace Metals with Runoff Volume

Station	Copper	Lead	Zinc	Chromium	N
LANDUSE					
L-1	0.143 +	0.816 +	0.008 -	0.003 +	5
L-2	0.838 -	0.114 +	0.069 -	0.001 +	5
L-3	0.116 +	0.014 -	0.073 -	0.226 +	6
L-4	0.002 -	0.332 -	0.917 +	0.125 -	4
L-5	0.170 +	0.130 +	0.915 +	0.115 +	7
L-6	0.460 +	0.018 +	0.176 +	0.244 -	6
STREAM					
S-1	0.750 +	0.572 +	0.424 +	0.688 +	7
S-2	0.143 +	0.218 +	0.211 +	0.187 +	7
S-3	0.352 +	0.213 +	0.300 +	0.542 +	7
S-4	0.373 +	0.508 +	0.274 +	0.448 +	6

6.3 CONVENTIONAL POLLUTANTS

Conventional pollutants are addressed in this section. These pollutants are not directly associated with the toxicity issues of principal concern, but have been conventionally used as measures of general water quality. An additional value in examining the concentration levels of these constituents is that they provide a general reference and a comparison of the intensive, but short-term, monitoring in this study, with watershed data collected at less-frequent intervals but spread out over a number of years.

In addition to providing a measure of water quality, in some cases these pollutants can provide information on and insight into the flow patterns that are present in the watershed. For example, surface runoff tends to have relatively low concentrations of Total Hardness (TH), while flows having a significant subsurface component exhibit significantly higher TH concentration levels.

Monitoring results for conventional pollutants are summarized by Table 6-2. Site median concentrations are listed for each of the monitoring sites, and also for the pooled data from selected groupings of individual sites. As reference to the tabulation of the individual event data (EMCs) presented in Appendix D will indicate, some of the pollutants were measured for only a single event at a site, providing a poor estimate of a representative concentration for that site. Thus, in the case of PO_4-P and NO_3, a value is shown only for the pooled data from all sites in the group.

6.3.1 Total Hardness, TSS, Turbidity, BOD, PO_4-P, and NO_3-N

Table 6-2 shows the SMCs of the conventional pollutants for each of the five residential/commercial land use sites, and then lists representative values for this land use category based on the use of the pooled EMC data from all the sites. The remaining land use categories to be used by the load estimating procedure are industrial (represented by site L2), and

Table 6-2. Study Results - Conventional Pollutants

Site Median Concentrations
mg / L

SITE	TSS	Turb	TH	BOD	PO4-P	NO3	TKN
Residential / Commercial Land Uses							
L-1	52	76	42	9.7			2.55
L-3	55	42	28	7.7			1.62
L-4	60	54	515	5.6			1.00
L-5	92	76	48	8.5			2.05
L-6	76	52	37	10.8			0.97
ALL Res/Com Sites (pooled data)							
	66	59	38 * *(w/o L-4)	8.3	0.26	0.62	1.54
Industrial Land Use Site							
L-2	134	116	40	11.8	0.68	0.55	1.63
Open Land Use Site							
L-7	22	21	233	4.4	0.19	0.18	0.75
Reservoir Releases	17	-	-	-	< 0.1	0.18	< 1
Stream Stations - WET WEATHER							
S-1	121	112	78	8.3			1.81
S-2	143	109	107	11.8			1.91
S-3	272	175	166	6.6			2.15
S-4	206	154	171	7.8			1.24
pool all	178	133	123	8.6	0.77	0.64	1.78
pool S1 and S2	133	110	93	10.1	0.71	0.50	1.85
Stream Stations - DRY WEATHER							
S-1	3	3	213	2.7	0.10	< 0.1	0.85
S-2	4	3	510	2.4	< 0.1	2.50	0.84
S-3	6	5	328	2.8	0.10	2.20	0.90
S-4	19	16	433	3.2	0.10	2.80	1.72
pool all	8	5	352	2.9	0.10	2.43	1.29
pool S1 and S2	3	3	329	2.5	< 0.1	1.30	1.01

undeveloped, open land (represented by site L7). SMC estimates for these use categories, provided by a single site, are less reliable than the estimate provided by the pooled residential/commercial data. However, the comparative differences between land use types suggests the approximation to be reasonable. Given the relatively small proportion of these uses (compared with residential/commercial uses) in the watershed below the reservoirs, the effect on annual load estimates is expected to be minor.

For the stream stations, both wet- and dry-weather concentrations are shown for each of the sampling locations. For comparative purposes, results are also shown for pooled data from all the stream stations, and also for stations S1 (Calabazas) and S2 (Sunnyvale East Channel). These two are separated and grouped for examination because they are mainly urban drainage channels without many of the other influences to which watercourses like the Guadalupe (S3) and Coyote (S4) are subject.

Water quality in the streams during wet-weather periods is about the same as in the runoff from land use sites for BOD and nutrients (PO_4-P, NO_3-N, and TKN). It is higher in TSS and turbidity. Stream Total Hardness levels are higher than concentrations in land use site runoff in most cases, implying a greater contribution from subsurface flows that are expected to be much higher in TH than surface runoff.

Stream concentrations during dry-weather periods are seen to be significantly lower than during storm runoff periods for all conventional pollutants, except TH. The higher levels during dry weather are consistent with the presence of a greater groundwater component of the total flow at these times.

Land use site L4 is seen to be abnormally high in TH. This suggests the presence of a relatively high proportion of subsurface flows in the runoff from this particular low-density residential land use site. The other conventional pollutants at this site compare well with the other use sites in the grouping.

There were additional pollutants analyzed that are not listed in Table 6-2, because meaningful results could not be presented in that format. For these pollutants, monitoring results are summarized below.

6.3.2 Ammonia (NH_3-N)

Ammonia was not detected (DL = 1.0 mg/L) in four dry-weather stream samples, and in only one of five stream samples during wet weather. The single detection by a more sensitive analytical test indicated a concentration of 0.2 mg/L.

Ammonia was not detected in any of the six reservoir samples.

For the land use sites, six of nine samples were below the detection limit (DL = 1.0 mg/L). For the remaining three samples, concentrations of 0.2, 0.2, and 0.6 mg/L were observed.

6.3.3 Nitrite (NO_2-N)

This is usually reported along with nitrate (NO_3) as a total combined concentration for the two forms. Observed concentrations were 5 to 10 percent of the reported nitrate values, as is typically the case, so the summary listing was limited to reporting only the nitrate values.

6.4 TRACE METALS

This section summarizes the results of the analysis of trace metal concentrations at the project monitoring sites. These pollutants are significant for the assessment of the toxicity issues.

The monitoring results for those trace metals that were found to be generally present at detectable concentrations are tabulated in this section. Site median concentrations are listed for each of the monitoring sites, and also for the pooled data from selected groupings of individual sites. There were additional trace metals analyzed that are not listed in the table presented, because a high percentage of the observations resulted in concentrations below the analytical detection limit. For these metals, meaningful results could not be presented in that format, and results are summarized in narrative form in Sections 6.4.1.2 to 6.4.1.6.

6.4.1 Results of Trace Metal Analyses

6.4.1.1 Cadmium, Chromium, Copper, Lead, Nickel, and Zinc. Monitoring results indicate that six trace metals (cadmium, chromium, copper, lead, nickel, and zinc) are generally present in detectable concentrations. Table 6-3 shows the SMCs of these trace metals for each of the five residential/commercial land use sites, and then lists representative values for this land use category based on the use of the pooled EMC data from all of the sites. The remaining land use categories to be used by the load estimating procedure are industrial (represented by site L2), and undeveloped, open land (represented by site L7). SMC estimates for these use categories, provided by a single site, are less reliable than the estimate provided by the pooled residential/commercial data. However, the comparative differences between land use types suggests the approximation to be reasonable. The open land use is much lower than the residential areas, which in turn has lower metal levels than the industrial site. Given the relatively small proportion of these uses (compared with residential/commercial uses) in the watershed below the reservoirs, the effect on annual load estimates is expected to be minor.

For the stream stations, both wet- and dry-weather concentrations are shown for each of the sampling locations. For comparative purposes, results are also shown for pooled data from all the stream stations, and also for stations S1 (Calabazas) and S2 (Sunnyvale East Channel). These two are separated and grouped for examination because they are mainly urban drainage channels without many of the other influences to which watercourses like the Guadalupe (S3) and Coyote (S4) are subject.

Table 6-3. Study Results - Trace Metals

Site Median Concentrations (ug/L)

SITE	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Residential / Commercial Land Uses						
L-1	1.0	13	35	63	47	231
L-3	1.3	7	22	47	15	213
L-4	1.0	25	22	4	25	47
L-5	1.8	16	33	44	23	295
L-6	1.6	24	47	49	27	239
ALL Res/Com Sites (pooled data)	1.3	14	31	37	25	200
Industrial Land Use Site						
L-2	5.5	33	49	121	48	1324
Open Land Use Site						
L-7	0.5	8	6	2	8	7
Reservoir Releases	< 0.2	5	6	2	6	6
Stream Stations - WET WEATHER						
S-1	2.0	22	47	39	47	249
S-2	1.7	25	42	39	32	287
S-3	1.4	25	48	52	65	179
S-4	2.2	35	53	53	75	174
pool all	1.8	36	55	76	65	251
pool S1 and S2	1.8	33	48	66	49	245
Stream Stations - DRY WEATHER						
S-1	0.2	2	7	1	2	12
S-2	0.4	3	3	1	2	9
S-3	0.2	3	3	2	2	8
S-4	0.2	4	6	1	2	14
pool all	0.3	3	5	1	2	10
pool S1 and S2	0.3	2	5	1	2	10

Trace metal concentrations in the streams during wet-weather periods are on the same order as in the runoff from land use sites, but about 50 to 100 percent higher.

To compare the water quality with representative background water quality, data from the open land use and reservoir sites are utilized as a general comparison. The open land use (L7) and reservoir locations are in open, undeveloped areas that are likely reasonable locations for background water quality. It is important to note that there are no background water quality data for areas in the residential commercial or industrial locations prior to development that we can use for comparisons.

Clearly, all the metals data from other land use types are higher than the open land use. For residential/commercial areas, the concentrations are higher by 3 (chromium) to 30 (zinc) times. For industrial land uses, the difference ranges from 6 (chromium) to 190 (zinc) times. The impact of background loads to the final estimated loads to the Bay is therefore likely small since both background concentrations and flows from open, undeveloped areas are expected to be extremely low.

During dry-weather periods, stream concentrations are about an order of magnitude lower than they are during storm runoff periods, and comparable to the concentration levels observed for the reservoir releases and the runoff from the open land use site.

Since only a minor component of the total volume of outflow to the Bay can be expected to result from dry-weather outflows, given the significant difference between dry and wet-weather concentrations, we may expect the non-stormwater-related streamflows to have a negligible contribution to the total mass loads delivered to the Bay.

An additional indication that water quality in the streams is influenced by factors other than the pollutants contributed by direct stormwater runoff is provided by the comparison of the quality of the first substantial storm of the wet season, relative to all of the other monitored events. This is illustrated by a temporal plot of measured flows over the 1-year monitoring period, on which measured concentrations are superimposed. Using zinc for the illustration, Figures 6-6a and 6-6b show results for the stream stations, and Figures 6-7a and 6-7b show results for four of the land use stations (L1, L3, L5, and L6). In the streams, concentrations during the first storm of the wet-weather season (November 23, 1988) are seen to be quite high relative to the other samples. This elevated concentration observed for the first storm may reflect the buildup of pollutants on the surface during the long dry period. Subsequent to the first storm, numerous storms occurred in December, which may likely have washed off the accumulated pollutants to result in a much lower concentration observed in the storm of January 23, 1989. The results indicated for zinc are representative of other trace metal pollutants (such as lead, copper, nickel, and chromium), as an inspection of the individual event concentrations tabulated in Appendix D will show. In contrast, this pattern is not shown by the land runoff sites.

There are other independent mechanisms at work influencing stream quality that do not exist in land use sites. The most likely postulated mechanisms are the scouring of stream banks or sediment deposits, which may be indirectly related in some degree to urban runoff.

The extent of sediment resuspension (or scouring of sediment deposits) during storm events in stream stations is represented in the TSS measurements. Using the pooled data from all stream stations, Figures 6-8a to 6-8d, show the correlations between the measured TSS concentrations and four metals (lead, chromium, copper, and zinc). The correlation coefficients of these relationships were significant, and ranged from 0.4 to 0.8. Generally, the larger amount of sediment resuspension, as indicated by the higher TSS levels, is associated with higher metal concentrations. Therefore, these significant correlations between TSS and

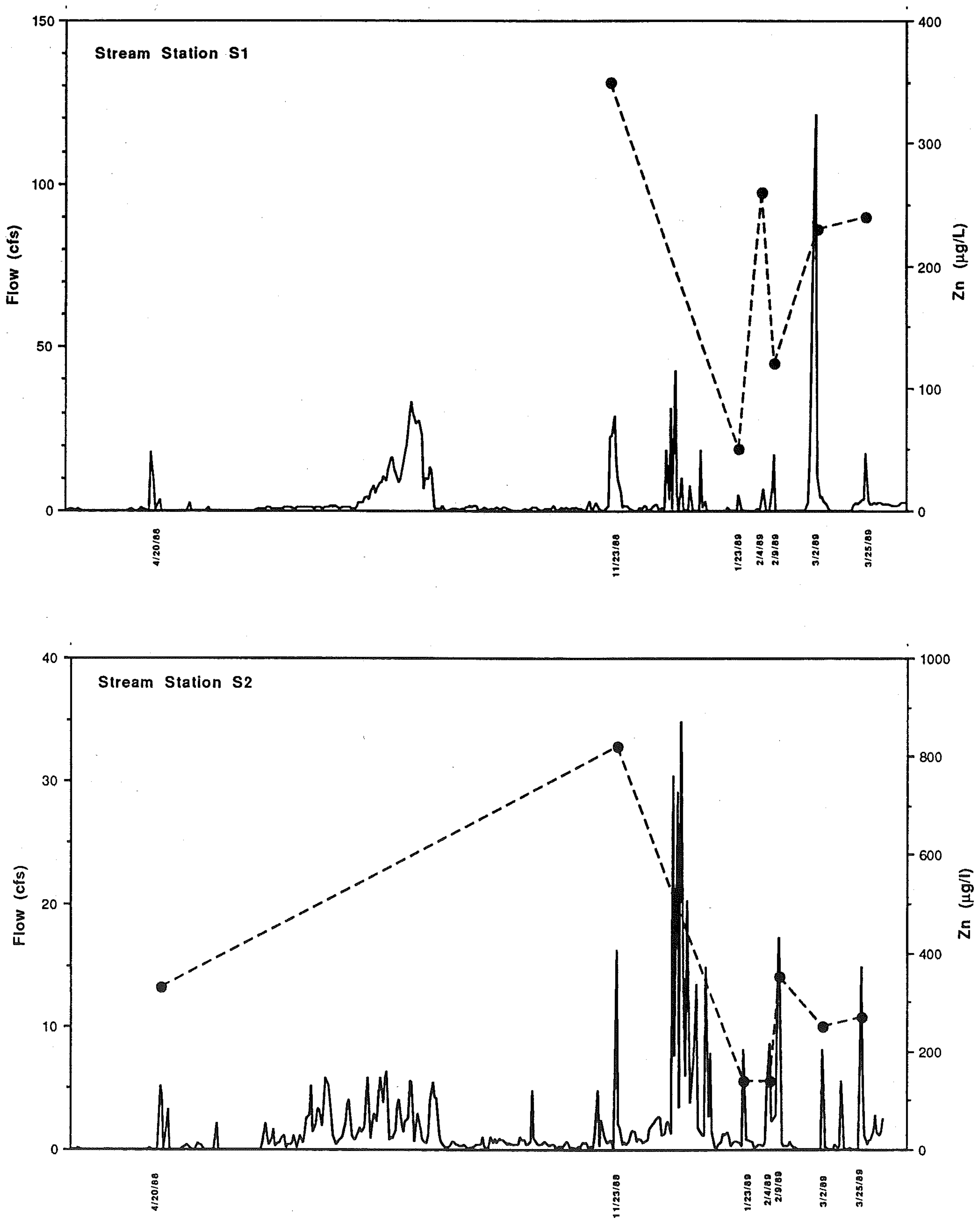


Figure 6-6a. Relationship Between Zinc Concentrations and Stream Flow from Stream Stations S-1 and S-2

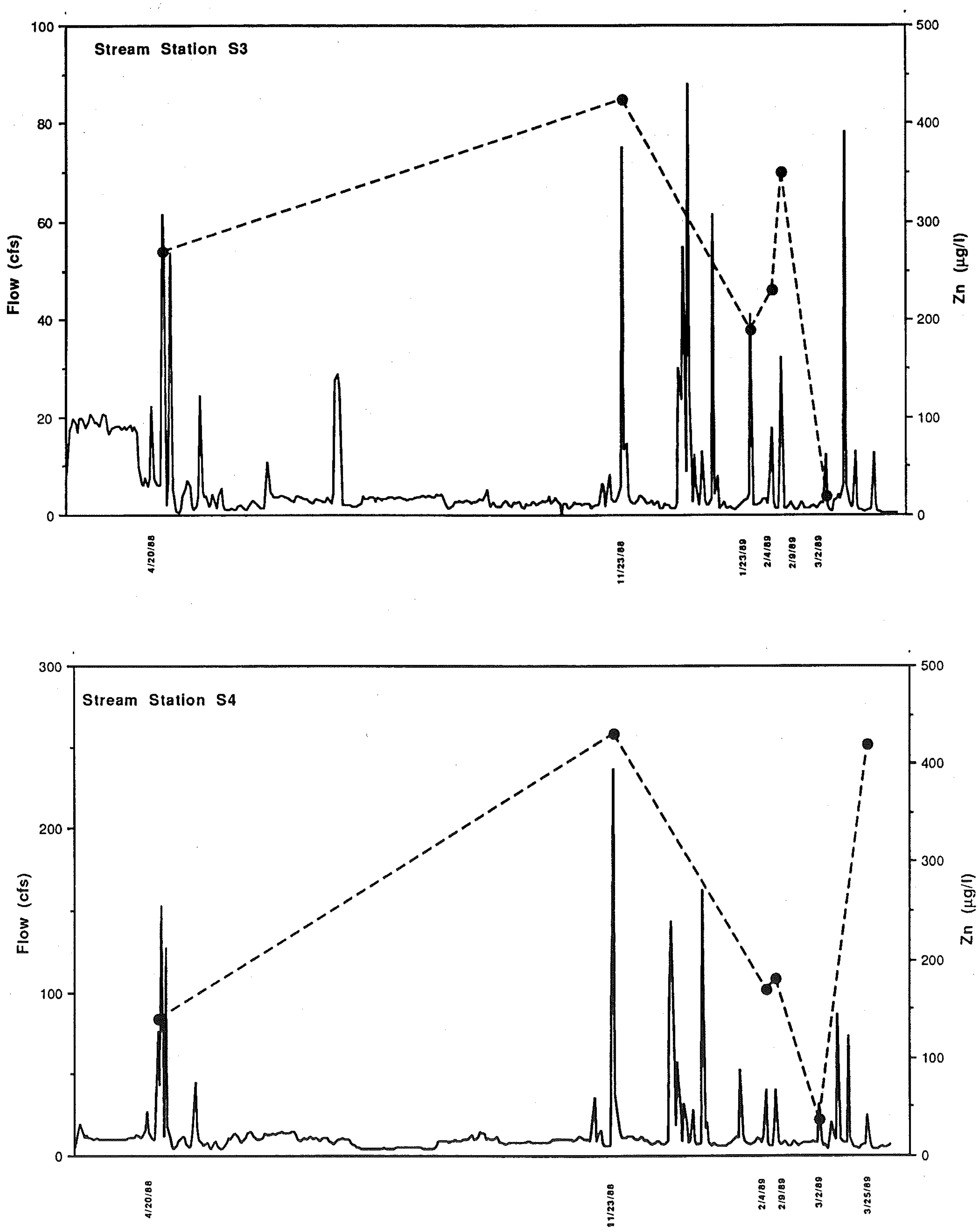


Figure 6-6b. Relationship Between Zinc Concentrations and Stream Flow from Stream Stations S-3 and S-4

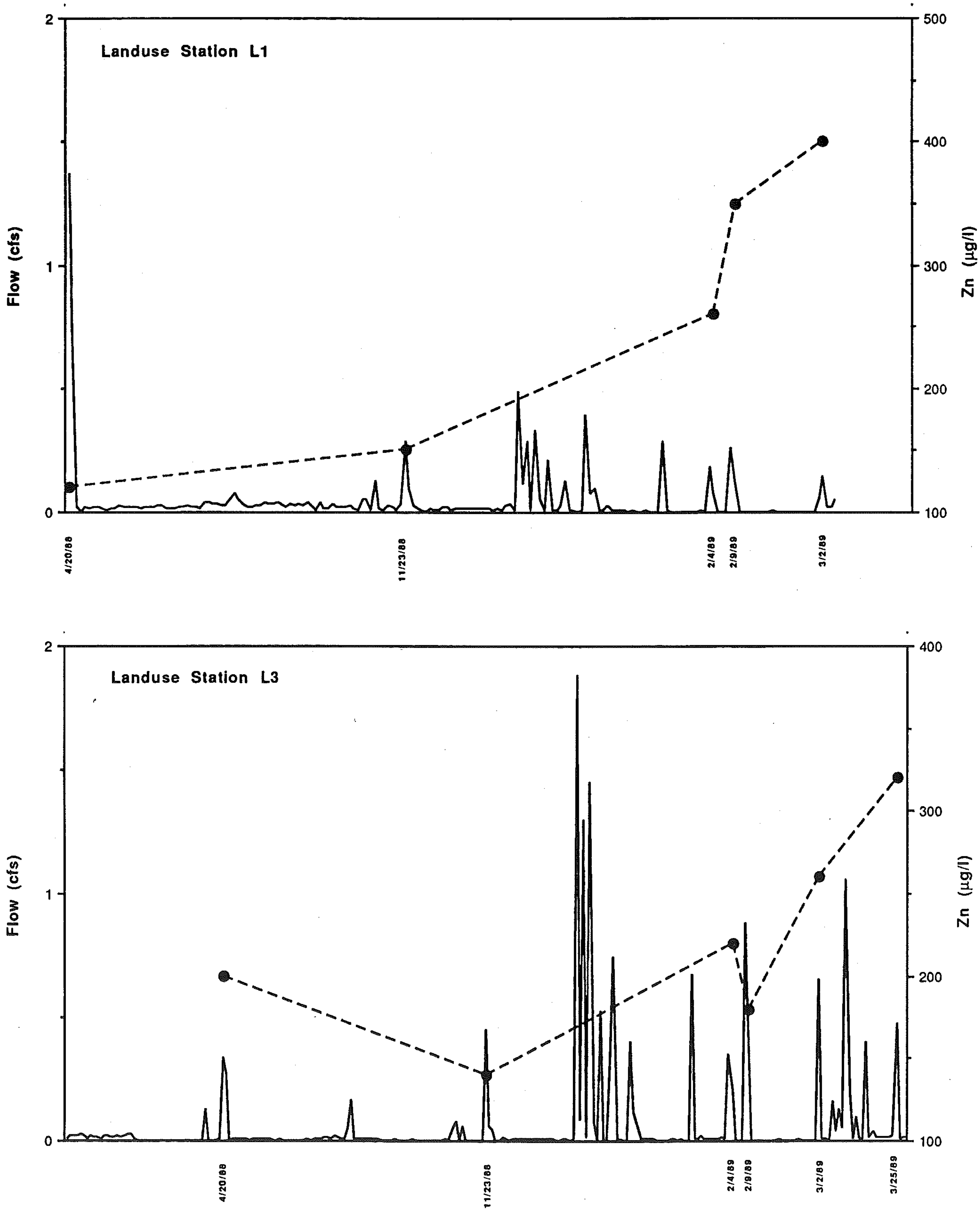
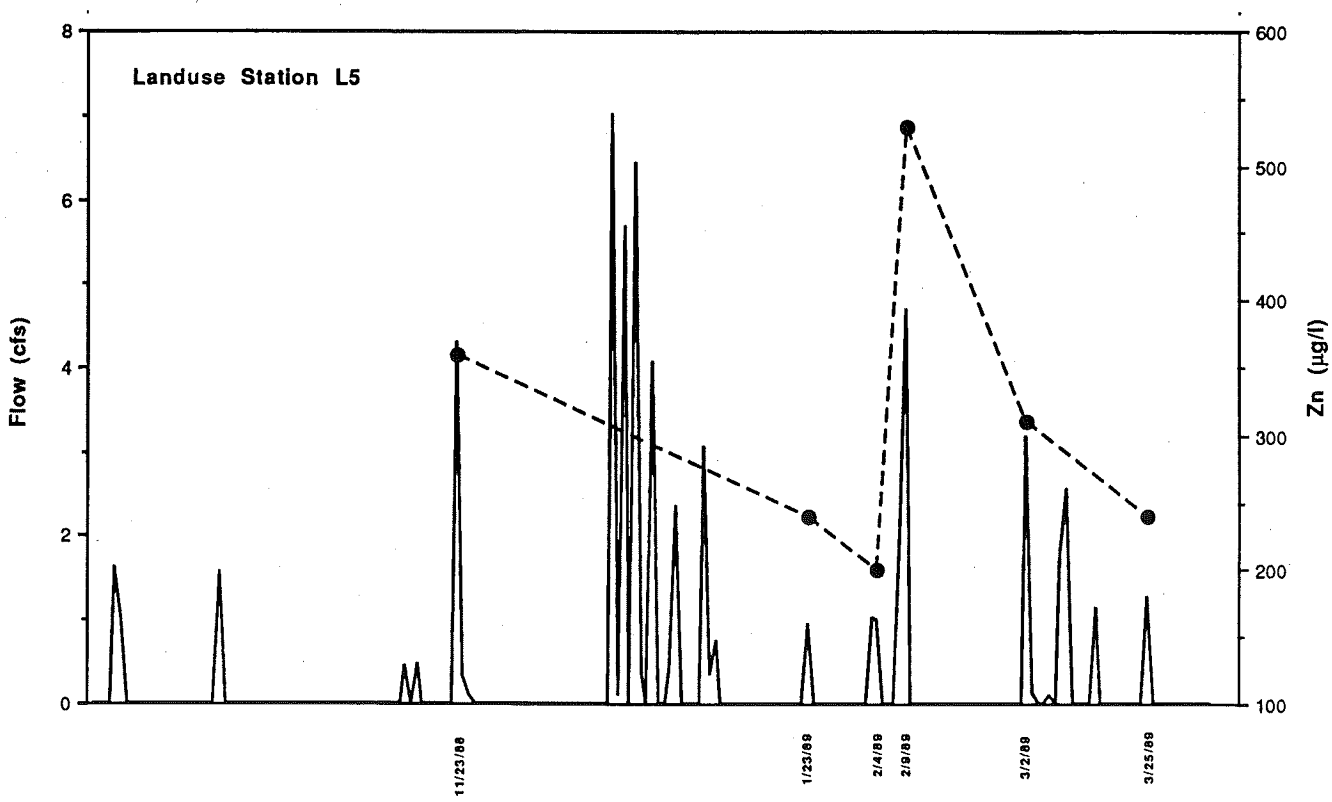


Figure 6-7a. Relationship Between Zinc Concentrations and Runoff Flow from Land Use Stations L-1 and L-3



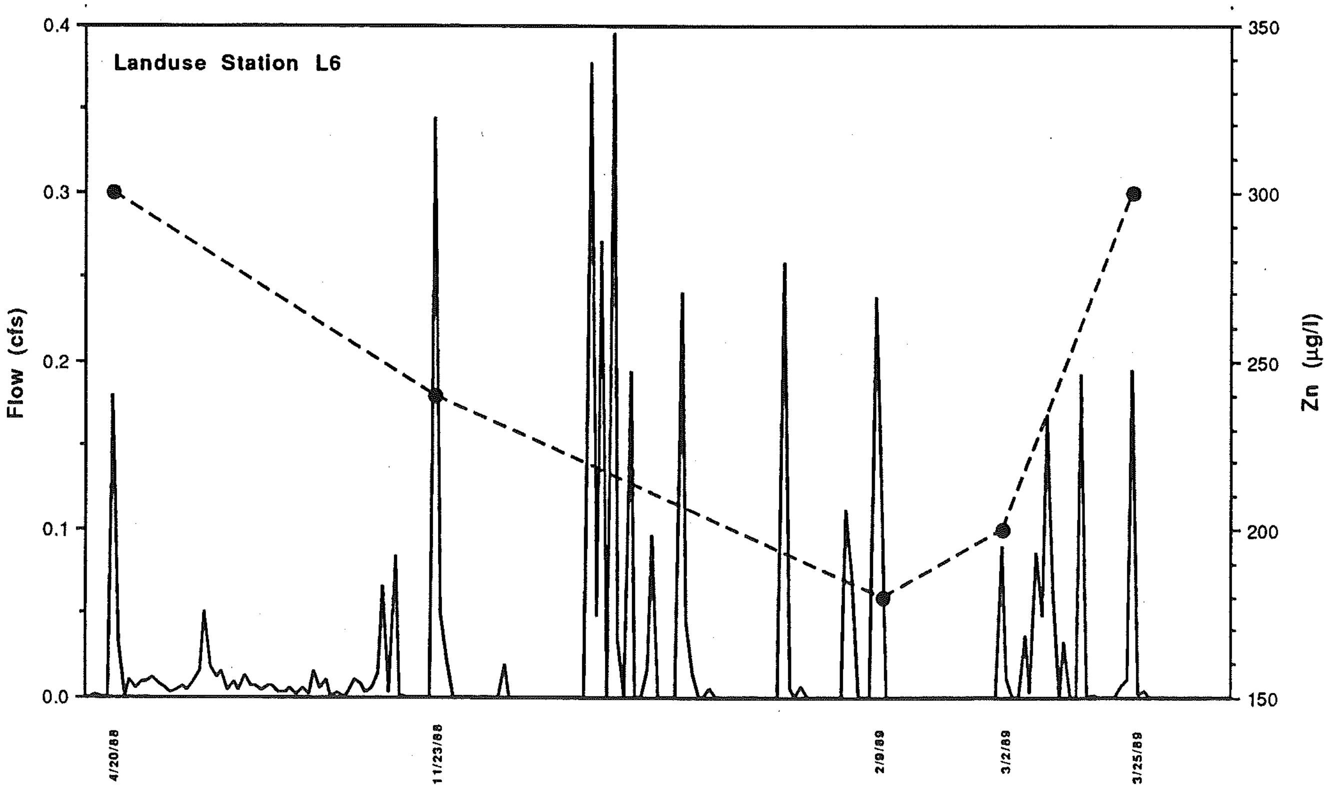


Figure 6-7b. Relationship Between Zinc Concentrations and Runoff Flow from Land Use Stations L-5 and L-6

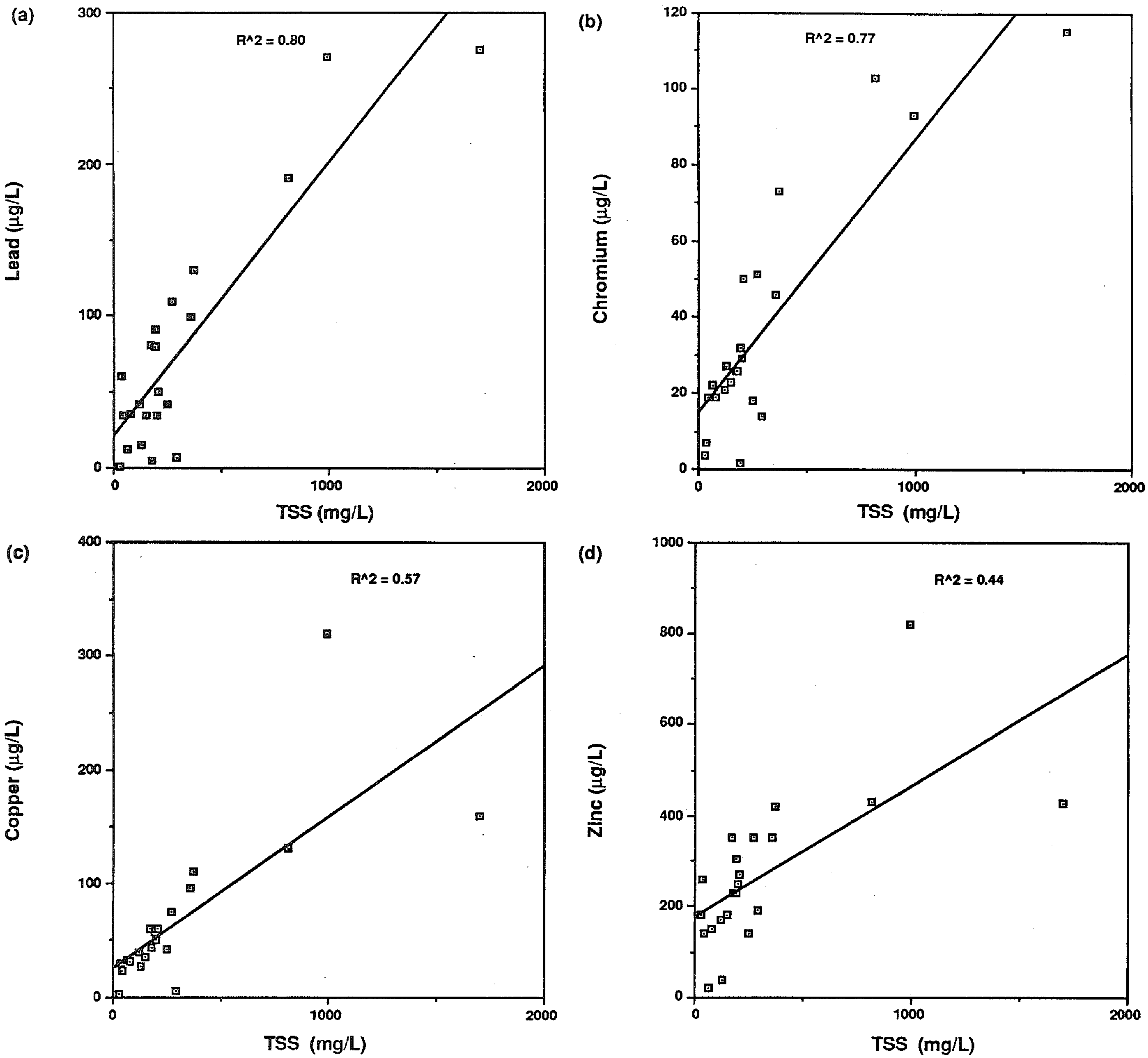


Figure 6-8. Relationship Between Metal Concentrations and TSS

metal concentrations indicate that the mechanism of sediment resuspension during storm events may play a major role in the total metal loads delivered to the Bay. The important sources of stream bed sediment pollution are not clear, but may include natural sources, illegal dumping and illicit connections, and stormwater runoff.

6.4.1.2 Arsenic (As) - (Detection Limit = 1 µg/L). Arsenic was detected in 6 of 12 dry-weather stream samples, and then at concentrations of 1 or 2 µg/L. In stream samples during wet weather, it was detected in only 7 of 24 samples. In 5 of the 7 samples, the concentration was 3 µg/L. The remaining values were 5 and 8 µg/L.

Arsenic concentrations in the reservoir release samples ranged between 1 and 7, with an average for the 6 samples of about 3 µg/L.

For the land use sites, 27 of 35 samples were below the detection limit. For the remaining 8 samples with detectable concentrations, observed values were in the range 1 to 4 µg/L.

6.4.1.3 Mercury (Hg) - (Detection Limit = 0.2 µg/L). Mercury was detected in only 3 of 26 dry-weather stream samples, at concentrations of 0.3, 2.3, and 2.5 µg/L. In stream samples during wet weather, it was detected in 13 of 24 samples. In these samples, the concentrations ranged between 0.2 and 4 µg/L.

Mercury was not detected in any of the 6 reservoir release samples.

For the land use sites, 17 of 35 samples were below the detection limit. For the remaining 16 samples with detectable concentrations, 10 of the observed values were less than 0.6 µg/L. The remaining 6 were between 1.1 and 4.4 µg/L.

6.4.1.4 Selenium (Se) - (Detection Limit varied from 0.2 to 0.5 μg/L). Selenium was detected in 10 of 26 dry-weather stream samples, at concentrations in the range of 0.25 to 10 μg/L. In stream samples during wet weather, it was detected in only 3 of 24 samples, and in each of these samples at concentrations of 1 μg/L.

Selenium was not detected in any of the 6 reservoir release samples.

For the land use sites, 31 of 35 samples were below the detection limit. For the remaining 4 samples, measured concentrations were between 0.4 and 1 μg/L.

6.4.1.5 Silver (Ag) - (Detection Limit = 0.2 μg/L). Silver was detected in 17 of 26 dry-weather stream samples, at concentrations in the range of 0.7 to 7.6 μg/L. In stream samples during wet weather, it was detected in 14 of 24 samples, at concentrations in the range of 0.2 to 2 μg/L.

Silver was detected in 5 of the 6 reservoir release samples, at concentrations in the range of 0.2 to 1.2 μg/L.

For the land use sites, 15 of 35 samples were below the detection limit. For the remaining 20 samples with detectable concentrations, 13 of the observed values were less than 0.5 μg/L. The remaining 7 were between 1 and 7 μg/L.

6.4.1.6 Hexavalent Chromium (Cr^{+6}) - (Detection Limit = 10 μg/L). Analytical tests for this form of chromium were made because the routine test for total chromium does not distinguish the species present. Although not expected to be present in runoff or streamflows, these tests were made to ensure that the proper toxic criteria would be applied for evaluating results. The trivalent form of chromium (Cr^{+3}), expected to be the form present in natural systems, is substantially less toxic to aquatic life than is the hexavalent form.

Hexavalent chromium was not detected in any of the 26 land runoff samples, 12 dry-weather stream samples, or 17 wet-weather stream samples.

6.4.2 Comparison with Toxic Criteria

The principal concern with trace metals introduced by storm runoff is their potential toxicity to aquatic organisms. As the data were obtained in the freshwater tributary streams, monitoring data are compared with EPA freshwater criteria. (An evaluation with saltwater criteria more representative of the Lower South Bay did not seem appropriate, given that effects of dilution and settling could not be adequately addressed.) Drinking-water criteria are not considered here because the streams do not serve as potable water sources.

Table 6-4 presents the EPA criteria for heavy metals, for both acute (short-term exposure) and chronic (extended exposure) effects on freshwater aquatic life. The values indicated are considered safe concentrations, i.e., levels which will not have an adverse effect if the concentrations are exceeded no more frequently than once in 3 years. Concentration levels that produce toxic effects vary appreciably with the total hardness (TH) of the water for a number of the trace metals. For these, the table lists the criterion value that corresponds to the observed TH at the various monitoring locations.

As indicated earlier, the order of magnitude of the concentration range of the different trace metals varies appreciably. Zinc levels are in the hundreds of micrograms per liter. Chromium, copper, lead, and nickel levels are in the tens of micrograms per liter. Arsenic, mercury, selenium, and silver are present at concentrations measured in tenths of a microgram per liter. To provide a perspective on the relative significance of the general concentration levels observed, each of the measured event mean concentrations (EMCs) has been compared with the appropriate criterion value, as a measure of its relative magnitude at its own level of significance.

Table 6-4. Water Quality Criteria for Heavy Metals

WET WEATHER ACUTE TOXIC CRITERIA

ACUTE EFFECTS USING FORMULA
CRITERION = EXP (A X Ln(Hardness) + B)

1. STREAM STATION S1 1 day conc µg/L

STORM EVENT	2	3	4	5	6	7
HARDNESS (mg/L)	110	240	110	55	76	56
CADMIUM	4.4	10.5	4.4	2.0	2.9	2.0
COPPER	19	40	19	10	14	10
LEAD	92	249	92	38	58	39
ZINC	348	664	348	196	256	199
NICKEL	1983	3588	1983	1171	1497	1187
CHROME (+3)	1877	3557	1877	1064	1387	1080
MERCURY	2.4	2.4	2.4	2.4	2.4	2.4
ARSENIC	360	360	360	360	360	360
SELENIUM	20	20	20	20	20	20
SILVER	-	-	-	-	-	-

2. STREAM STATION S2

STORM EVENT	2	3	4	5	6	7
HARDNESS (mg/L)	330	103	74	76	88	77
CADMIUM	15.1	4.1	2.8	2.9	3.4	2.9
COPPER	55	18	13	14	16	14
LEAD	373	85	56	58	69	59
ZINC	865	329	250	256	289	259
NICKEL	4570	1886	1467	1497	1674	1512
CHROME (+3)	4617	1779	1357	1387	1564	1402

3. STREAM STATION S3

STORM EVENT	2	3	4	5	6	7
HARDNESS (mg/L)	180	130	130	140	300	NA
CADMIUM	7.6	5.3	5.3	5.7	13.5	NC
COPPER	31	23	23	24	50	NC
LEAD	173	114	114	125	331	NC
ZINC	523	399	399	425	800	NC
NICKEL	2883	2251	2251	2382	4251	NC
CHROME (+3)	2810	2153	2153	2287	4270	NC

4. STREAM STATION S4

STORM EVENT	2	3	4	5	6	7
HARDNESS (mg/L)	190	NA	160	140	140	200
CADMIUM	8.1	NC	6.7	5.7	5.7	8.6
COPPER	32	NC	28	24	24	34
LEAD	185	NC	149	125	125	197
ZINC	547	NC	475	425	425	571
NICKEL	3004	NC	2636	2382	2382	3124
CHROME (+3)	2937	NC	2552	2287	2287	3064

Equation Constants:

A	B	METAL
1.1280	-3.8280	CADMIUM
0.9422	-1.4640	COPPER
1.2730	-1.4600	LEAD
0.8300	1.9500	ZINC
0.7600	4.0200	NICKEL
0.8190	3.6880	CHROME (+3)
*	*	MERCURY, ARSENIC, SELENIUM, SILVER

(*) indicates that criterion is not influenced by hardness
NA Not Analyzed NC Not Calculated
Hardness was not measured for wet weather event 1; lowest criterion assumed for comparisons

Table 6-4. Water Quality Criteria for Heavy Metals (Cont'd)

DRY WEATHER CHRONIC TOXIC CRITERIA

CHRONIC EFFECTS USING FORMULA

CRITERION = EXP (A X Ln(Hardness) + B)

1. STREAM STATION S1	4 day conc µg/L		
DRY EVENT	**5**	**6**	**7**
HARDNESS (mg/L)	230	190	220
CADMIUM	2.2	1.9	2.1
COPPER	24	20	23
LEAD	9	7	9
ZINC	47	47	47
NICKEL	180	156	174
CHROME (+3)	409	350	395
MERCURY	0.012	0.012	0.012
ARSENIC	190	190	190
SELENIUM	5	5	5
2. STREAM STATION S2			
HARDNESS (mg/L)	500	530	500
CADMIUM	4.0	4.2	4.0
COPPER	47	49	47
LEAD	25	27	25
ZINC	47	47	47
NICKEL	325	339	325
CHROME (+3)	773	811	773
3. STREAM STATION S3			
HARDNESS (mg/L)	330	360	295
CADMIUM	2.9	3.1	2.7
COPPER	33	35	30
LEAD	15	16	13
ZINC	47	47	47
NICKEL	237	253	217
CHROME (+3)	550	591	502
4. STREAM STATION S4			
HARDNESS (mg/L)	460	420	420
CADMIUM	3.8	3.5	3.5
COPPER	44	40	40
LEAD	22	20	20
ZINC	47	47	47
NICKEL	305	284	284
CHROME (+3)	722	670	670

Equation Constants:	A	B	METAL
	0.7852	-3.49	CADMIUM
	0.8545	-1.465	COPPER
	1.273	-4.705	LEAD
	0.76	1.06	NICKEL
	0.819	1.561	CHROME (+3)
	*	*	MERCURY, ARSENIC, SELENIUM, SILVER, ZINC

(*) indicates that criterion is not influenced by hardness
Hardness was not measured for dry events 1 through 4; lowest criterion assumed for comparisons.

Table 6-4. Water Quality Criteria for Heavy Metals (Cont'd)

WET WEATHER ACUTE TOXIC CRITERIA

ACUTE EFFECTS USING FORMULA
CRITERION = EXP (A X Ln(Hardness) + B)

1. LANDUSE STATION L1

STORM EVENT	2	4	5	6	7
HARDNESS (mg/L)	31	32	36	88	NA
CADMIUM	1.0	1.1	1.2	3.4	NC
COPPER	6	6	7	16	NC
LEAD	18	19	22	69	NC
ZINC	122	125	138	289	NC
NICKEL	757	776	849	1674	NC
CHROME (+3)	665	683	752	1564	NC
MERCURY	2.4	2.4	2.4	2.4	NC
ARSENIC	360	360	360	360	NC
SELENIUM	20	20	20	20	NC

2. LANDUSE STATION L2

HARDNESS (mg/L)	47	42	33	47	35
CADMIUM	1.7	1.5	1.1	1.7	1.2
COPPER	9	8	6	9	7
LEAD	31	27	20	31	21
ZINC	172	156	128	172	134
NICKEL	1039	954	794	1039	831
CHROME (+3)	936	853	700	936	735

3. LANDUSE STATION L3

HARDNESS (mg/L)	33	32	26	25	26
CADMIUM	1.1	1.1	0.9	0.8	0.9
COPPER	6	6	5	5	5
LEAD	20	19	15	14	15
ZINC	128	125	105	102	105
NICKEL	794	776	663	643	663
CHROME (+3)	700	683	576	558	576

3. LANDUSE STATION L4

HARDNESS (mg/L)	NA	530	470	NA	550
CADMIUM	NC	25.7	22.5	NC	26.8
COPPER	NC	85	76	NC	88
LEAD	NC	682	585	NC	715
ZINC	NC	1282	1161	NC	1322
NICKEL	NC	6551	5979	NC	6738
CHROME (+3)	NC	6805	6168	NC	7015

Equation Constants:

A	B	METAL
1.1280	-3.8280	CADMIUM
0.9422	-1.4640	COPPER
1.2730	-1.4600	LEAD
0.8300	1.9500	ZINC
0.7600	4.0200	NICKEL
0.8190	3.6880	CHROME (+3)
*	*	MERCURY, ARSENIC, SELENIUM, SILVER

(*) indicates that criterion is not influenced by hardness

NA Not Analyzed NC Not Calculated

Hardness was not measured for wet events 1 and 3; lowest criterion assumed for comparisons.

Table 6-4. Water Quality Criteria for Heavy Metals (Concluded)

WET WEATHER ACUTE TOXIC CRITERIA

ACUTE EFFECTS USING FORMULA

CRITERION = EXP (A X Ln(Hardness) + B)

4. LANDUSE STATION L5

STORM EVENT	2	3	4	5	6	7
HARDNESS (mg/L)	79	51	45	41	47	36
CADMIUM	3.0	1.8	1.6	1.4	1.7	1.2
COPPER	14	9	8	8	9	7
LEAD	60	35	30	26	31	22
ZINC	264	184	166	153	172	138
NICKEL	1542	1106	1005	937	1039	849
CHROME (+3)	1432	1000	903	837	936	752

5. LANDUSE STATION L6

HARDNESS (mg/L)	56	NA	NA	25	35	37
CADMIUM	2.0	NC	NC	0.8	1.2	1.3
COPPER	10	NC	NC	5	7	7
LEAD	39	NC	NC	14	21	23
ZINC	199	NC	NC	102	134	141
NICKEL	1187	NC	NC	643	831	866
CHROME (+3)	1080	NC	NC	558	735	769

6. LANDUSE STATION L7

HARDNESS (mg/L)	260	NA	250	250	250	170
CADMIUM	11.5	NC	11.0	11.0	11.0	7.1
COPPER	44	NC	42	42	42	29
LEAD	276	NC	262	262	262	160
ZINC	710	NC	687	687	687	499
NICKEL	3813	NC	3701	3701	3701	2761
CHROME (+3)	3798	NC	3678	3678	3678	2682

Equation Constants:

A	B	METAL
1.1280	-3.8280	CADMIUM
0.9422	-1.4640	COPPER
1.2730	-1.4600	LEAD
0.8300	1.9500	ZINC
0.7600	4.0200	NICKEL
0.8190	3.6880	CHROME (+3)
*	*	MERCURY, ARSENIC, SELENIUM, SILVER

(*) indicates that criterion is not influenced by hardness

NA Not Analyzed NC Not Calculated

Hardness was not measured for wet event 1; lowest criterion assumed for comparisons.

Table 6-5 indicates the proportion of the total observations that exceed the appropriate criterion value, for the land runoff stations and the reservoir outlets. For these samples, which represent intermittent, short-duration runoff events, the acute toxicity criterion is applied. There is no formal criterion for silver, and although TH measurements were not made for the reservoir samples, the concentrations of all metals were low enough to be well below the most restrictive criteria estimates. For the others, the tabulation indicates that no acute criteria exceedances were observed for nickel, arsenic, chromium, or selenium. For mercury, only 2 of 35 observations exceeded the 2.4 μg/L acute level, in 1 event each at sites L2 and L5.

Storm runoff from land use stations frequently exceeds the criteria for copper, lead, zinc, and cadmium, at all but the open land use site (L7) and residential site L4 . At these latter sites, the combination of lower metal concentrations and higher TH levels prevents exceedances. A significant factor in the exceedance frequency for this group of metals is the very low TH levels (about 40 mg/L as $CaCO_3$) in the surface stormwater runoff, which results in quite restrictive toxic levels.

For runoff from the urban areas, the principal value in the foregoing table is in its use as a reference for the relative magnitude of concentration levels for the range of pollutants examined. The evaluation of the actual use impairment potential of these metal discharges is more appropriately made by a similar examination of the measured stream data.

Table 6-6 lists criteria exceedance frequency at the monitored stream stations. Wet-weather event data are compared with acute criteria, and dry-weather results are compared with the more restrictive chronic criteria. Wet weather stream water quality data should only be compared with the acute criteria because of the relative short duration of the bulk of typical storm runoff events. Although storm runoff from streams may

Table 6-5. Comparison of Monitored Event Concentrations from Landuse Stations with EPA Toxic Criteria

	Runoff from Landuse Sites Exceedances / Total Observations									
	Copper µg/L	Lead µg/L	Nickel µg/L	Zinc µg/L	Arsenic µg/L	Cadmium µg/L	Chromium µg/L	Mercury µg/L	Selenium µg/L	Silver µg/L
Residential/Commercial Land Uses										
L1	5 / 5	4 / 5	0 / 5	3 / 5	0 / 5	2 / 5	0 / 5	0 / 5	0 / 5	0 / 5
L3	6 / 6	6 / 6	0 / 6	6 / 6	0 / 6	4 / 6	0 / 6	0 / 6	0 / 6	0 / 6
L4	0 / 3	0 / 3	0 / 3	0 / 3	0 / 3	0 / 3	0 / 3	0 / 3	0 / 3	0 / 3
L5	5 / 6	5 / 6	0 / 6	6 / 6	0 / 6	2 / 6	0 / 6	1 / 6	0 / 6	0 / 6
L6	5 / 5	4 / 5	0 / 5	5 / 5	0 / 5	3 / 5	0 / 5	0 / 5	0 / 5	0 / 5
Industrial Land Use Site										
L2	5 / 5	5 / 5	0 / 5	5 / 5	0 / 5	5 / 5	0 / 5	1 / 5	0 / 5	0 / 5
Open land Use Site										
L7	0 / 5	0 / 5	0 / 5	0 / 5	0 / 5	0 / 5	0 / 5	0 / 5	0 / 5	0 / 5
Reservoir Stations	0 / 6	0 / 6	0 / 6	0 / 6	0 / 6	0 / 6	0 / 6	0 / 6	0 / 6	0 / 6

Table 6-6. Comparison of Monitored Event Concentrations from Stream Stations with EPA Toxic Criteria

	Stream Stations Exceedances / Total Observations									
	Copper µg/L	**Lead** µg/L	**Nickel** µg/L	**Zinc** µg/L	**Arsenic** µg/L	**Cadmium** µg/L	**Chromium** µg/L	**Mercury** µg/L	**Selenium** µg/L	**Silver** µg/L
Dry Weather										
S1	1 / 6	0 / 6	0 / 3	1 / 6	0 / 3	0 / 3	0 / 3	*	0 / 6	0 / 6
S2	0 / 6	0 / 6	0 / 3	0 / 6	0 / 3	0 / 3	0 / 3	*	1 / 6	0 / 6
S3	0 / 7	0 / 7	0 / 3	0 / 7	0 / 3	0 / 3	0 / 3	*	0 / 7	0 / 7
S4	0 / 7	0 / 7	0 / 3	0 / 7	0 / 3	0 / 3	0 / 3	*	0 / 7	0 / 7
Wet Weather										
S1	5 / 5	2 / 5	0 / 5	2 / 5	0 / 5	1 / 5	0 / 5	0 / 5	0 / 5	0 / 5
S2	6 / 7	0 / 7	0 / 7	2 / 7	0 / 7	2 / 7	0 / 7	1 / 7	0 / 7	0 / 7
S3	4 / 6	1 / 6	0 / 6	0 / 6	0 / 6	0 / 6	0 / 6	1 / 6	0 / 6	0 / 6
S4	6 / 6	1 / 6	0 / 6	0 / 6	0 / 6	0 / 6	0 / 6	1 / 6	0 / 6	0 / 6

last for about 2 days, the rising limb of the hydrograph and the peak flow occurs in the early phase of the storm lasting about 12 hours. During the early part of the storm, where high flows occur, the pollutant concentration is expected to be high due to rapid resuspension of stream sediments. However, as flow decreases, rapid settling of suspended solids in the water column would result in a decrease in pollutant concentrations. Since storm water runoff events are of relatively short duration, the chronic criteria which are applicable to long-term exposure typical of dry weather water quality is likely not applicable.

The TH during dry periods is significantly higher than during storm runoff periods. Results indicate that during dry weather, concentrations of all pollutants are generally less than chronic toxicity criteria values. There were only three exceptions: a single copper exceedance at S1, a single zinc exceedance at S1, and a single selenium exceedance at S2. No exceedances of chronic criteria were observed in the Guadalupe or Coyote. No determination could be made for mercury, because while all observations were below the detection limit of 0.2 μg/L, the criterion value (0.012 μg/L) is much lower.

The following four sections discuss the exceedances of the acute criteria for all wet weather events.

6.4.2.1 Arsenic, Chromium, Nickel, and Selenium. During storm runoff periods, no criteria exceedances are noted for arsenic, nickel, chromium or selenium. Since the same result was obtained for the land use samples, these metals appear to have little or no significance to the pollutant loading issues associated with urban runoff in this Study Area.

6.4.2.2 Mercury. Occasional (3 of 24) wet-weather exceedances of the acute criteria are observed for mercury, with one value each at three of the four stream stations. Since results were comparable (2 of 35), the results suggest mercury to be present at marginal levels of potential concern. Since the wet-weather samples confirm its presence, the possibility of chronic levels being present during dry weather is suggested, although the analytical test sensitivity is not sufficient to confirm it.

6.4.2.3 Cadmium and Zinc. Cadmium and zinc wet-weather exceedances occur at S1 and S2, but not in the Coyote (S4) or Guadalupe (S3). Cadmium exceedances are relatively infrequent (3 of 24). Concentration levels are similar in all streams, the difference resulting from the higher TH, and hence criteria values for the Guadalupe and Coyote channels. The pattern is similar for zinc, except that the exceedances in S1 and S2 occur more frequently (4 of 24). These two metals are indicated to warrant moderate levels of concern in terms of overall quality and loading issues. They do not appear to be highly significant to the biological integrity of the Guadalupe or Coyote.

6.4.2.4 Copper and Lead. At all stream stations, the copper criterion is exceeded at high frequency (22 of 24) during wet-weather events. The lead criterion is also exceeded at all stations, though at appreciably lower frequencies (4 of 24). These two metals, and copper in particular, appear to be the inorganic toxic pollutants of most concern in runoff from the Study Area, based on the indicated frequency of exceedances. The concentration levels at which they are present in runoff are not particularly high. Copper SMCs are near the median reported by the NURP program for urban sites throughout the country. Lead SMCs are in the lowest quartile of the NURP study results. The indicated toxic potential results from a combination of the levels present and the TH concentrations of the Study Area waters.

This analysis suggests that copper and lead (and to a lesser extent, cadmium and zinc) are the most appropriate trace metals to consider in a general assessment of stormwater loads and their potential for causing adverse water quality impacts. However, for assessing the potential problems caused by metals in the tributary streams, the analysis can be extended, by considering the soluble fraction of the total metal concentrations which have been used in all of the preceding summaries. The EPA criteria are based on the acid soluble fraction of a metal, which concentration would be lower than the total, and higher than the soluble fraction. Comparisons with the EPA criteria using both total and soluble fractions of metals measured in this study would result in exceedances that are intermediate in value.

6.4.3 Soluble Fraction of Trace Metals

For two wet-weather events (events 6 and 7), runoff and stream samples were analyzed for dissolved metal concentrations, in addition to the total concentrations that were routinely measured. With only a few exceptions, observed soluble concentrations were appreciably lower than the total levels (particulate plus dissolved forms) for the same sample. The exceptions include selenium, most of which appears to be present in the dissolved form, and a number of the metals in the discharge from the open land use site (station L7).

In general, dissolved concentrations were very low, or below the detection limit. Arsenic, chromium, and mercury were not detected in any of the samples. Soluble lead was not detected in any of the stream samples, and was above the detection limit in only 5 of the 12 runoff samples. Dissolved silver was detected in 4 of 12 runoff samples and in 3 of 7 stream samples.

Analysis results are summarized in Tables 6-7, 6-8, and 6-9, which list both soluble (SOL) and total (TOT) concentrations. Where it was possible, the soluble fraction (%SOL) has been computed and listed in the table. For cases where both the TOT and SOL are non-detects, the %SOL is not computed and the entry has been left blank. There are, however, a number of cases involving a non-detect value where the difference between the detection limit and the observed total concentration is great enough to provide useful information, if not an exact result. These report the soluble fraction to be less than the indicated percentage (e.g., <13 percent).

Table 6-7. Soluble Fraction of Trace Metals, Copper, Lead, Nickel and Zinc in Wet Weather Samples

		COPPER			LEAD			NICKEL			ZINC		
Station	Event No.	SOL	TOT	% SOL	SOL	TOT	% SOL	SOL	TOT	% SOL	SOL	TOT	% SOL
	DL =	1	1		1	1		2	2		1		
RESIDENTIAL / COMMERCIAL SITES													
L1	6	10	55	18%	5	35	14%	17	450	4%	300	400	75%
L3	6	9	33	27%	< 1	35	< 3%	< 2	30	< 7%	100	260	38%
L3	7	6	22	27%	< 1	55	< 2%	4	40	10%	100	320	31%
L4	7	2	33	6%	< 1	7	< 14%	8	60	13%	5	20	25%
L5	6	11	50	22%	< 1	48	< 2%	3	55	5%	95	315	30%
L5	7	7	44	16%	2	110	2%	5	60	8%	100	240	42%
L6	6	9	39	23%	< 1	30	< 3%	4	110	4%	100	200	50%
L6	7	9	55	16%	3	130	2%	8	70	11%	100	300	33%
OPEN SITE													
L7	6	4	4	100%	< 1	1		< 2	6		3	5	60%
L7	7	9	11	82%	< 1	3		6	90	7%	7	12	58%
INDUSTRIAL SITE													
L2	6	13	60	22%	2	110	2%	6	80	8%	800	2000	40%
L2	7	10	39	26%	3	75	4%	8	80	10%	200	700	29%
STREAM MONITORING SITES													
S1	6	10	44	23%	< 1	5	< 20%	< 2	100	< 2%	100	230	43%
S1	7	7.5	58	13%	< 1	80	< 2%	5	100	5%	40	305	13%
S2	6	11	50	22%	< 1	35	< 3%	< 2	120	< 2%	100	250	40%
S2	7	8	60	13%	< 1	50	< 2%	5	90	6%	40	270	15%
S3	6	6	33	18%	< 1	12	< 8%	6	80	8%	17	19	89%
S4	6	7	27	26%	< 1	15	< 7%	8	120	7%	<1	36	< 3%
S4	7	6	110	5%	< 1	130	< 1%	6	150	4%	16	420	4%

Table 6-8. Soluble Fraction of Trace Metals, Cadmium, Chromium, Selenium, and Silver in Wet Weather Samples

		CADMIUM			CHROMIUM			SELENIUM			SILVER		
Station	Event	SOL	TOT	% SOL	SOL	TOT	% SOL	SOL	TOT	% SOL	SOL	TOT	% SOL
	No. DL =	0.2	0.2		1	1		0.2			0.2	0.2	
RESIDENTIAL / COMMERCIAL SITES													
L1	6	5	0.5		8	12	67%	< 0.2	< 0.2		6	1	
L3	6	0.3	1.2	25%	1	8	13%	< 0.2	< 0.2		< 0.2	< 0.2	
L3	7	< 0.2	1.3	< 15%	1	15	7%	< 0.2	< 0.2		< 0.2	< 0.2	
L4	7	< 0.2	0.6	< 33 %	4	23	17%	1	1		2	3	67%
L5	6	0.2	1.25	16%	1	17	6%	< 0.2	< 0.2		< 0.2	< 0.2	
L5	7	< 0.2	1.1	< 18%	2	19	11%	< 0.2	< 0.2		< 0.2	0.2	
L6	6	< 0.2	1.5	< 13%	1	74	1%	< 0.2	< 0.2		< 0.2	< 0.2	
L6	7	0.3	1.4	21%	2	23	9%	< 0.2	< 0.2		< 0.2	0.2	
OPEN SITE													
L7	6	< 0.2	< 0.2		1	5	20%	< 0.2	1	< 20%	< 0.2	0.2	
L7	7	< 0.2	0.2		1	22	5%	< 0.2	< 0.2		0.2	0.3	67%
INDUSTRIAL SITE													
L2	6	1	9.5	11%	6	38	16%	< 0.2	< 0.2		< 0.2	1	< 20%
L2	7	< 0.2	4.7	< 4%	6	38	16%	< 0.2	< 0.2		0.5	2	25%
STREAM MONITORING SITES													
S1	6	0.2	1.1	18%	1	26	4%	1	1	100%	< 0.2	0.2	
S1	7	< 0.2	1.4	< 14%	1	32	3%	< 0.2	< 0.2		< 0.2	0.2	
S2	6	0.3	1.4	21%	1	29	3%	< 0.2	< 0.2		< 0.2	0.3	
S2	7	< 0.2	1.5	< 13%	1	50	2%	< 0.2	< 0.2		< 0.2	0.4	
S3	6	0.2	0.7	29%	3	22	14%	1	1	100%	0.2	0.4	50%
S4	6	0.2	1.2	17%	1	27	4%	1	1	100%	0.2	0.3	67%
S4	7	< 0.2	4	< 5%	1	73	1%	< 0.2	< 0.2		0.4	2	20%

Table 6-9. Soluble Fraction of Trace Metals, Mercury and Arsenic, in Wet Weather Samples

Station	Event No.		MERCURY		ARSENIC		
			SOL	TOT	SOL	TOT	% SOL
		DL =	0.2	0.2	1	1	
RESIDENTIAL / COMMERCIAL SITES							
L1	6		< 0.2	0.2	<1	<1	
L3	6		< 0.2	0.2	<1	<1	
L3	7		< 0.2	0.2	<1	<1	
L4	7		< 0.2	< 0.2	<1	<1	
L5	6		< 0.2	0.2	<1	<1	
L5	7		< 0.2	< 0.2	<1	<1	
L6	6		< 0.2	< 0.2	<1	2	< 50%
L6	7		< 0.2	< 0.2	<1	2	< 50%
OPEN SITE							
L7	6		< 0.2	0.2	<1	4	< 25%
L7	7		< 0.2	< 0.2	<1	<1	
INDUSTRIAL SITE							
L2	6		< 0.2	< 0.2	<1	<1	
L2	7		< 0.2	< 0.2	<1	1	
STREAM MONITORING SITES							
S1	6		< 0.2	0.2	<1	3	< 30%
S1	7		< 0.2	0.2	<1	3	< 30%
S2	6		< 0.2	< 0.2	<1	3	< 30%
S2	7		< 0.2	< 0.2	<1	<1	
S3	6		< 0.2	< 0.2	<1	<1	
S4	6		< 0.2	< 0.2	<1	<1	
S4	7		< 0.2	< 0.2	<1	8	< 13%

The data limitations are too great to justify a formal analysis of the results, but appear sufficient to provide a reliable indication of the approximate soluble fraction for some of the metals. It was earlier suggested from the criteria comparisons that copper and lead may be the metals of most significance in the watershed. These results suggest that the soluble fraction for copper (together with cadmium and chromium) is on the order of 15 to 25 percent in both runoff and stream samples. For lead, the indications are that less than 5 percent of the total present is in dissolved form. The soluble fraction for nickel appears to be intermediate at 5 to 15 percent. Zinc has a soluble fraction in the range of 30 to 50 percent. All of the estimates appear reasonable, but those for copper, zinc, and chromium are the most reliable because all of the concentrations measured are above the detection limits.

If the criteria exceedance frequency presented earlier is reexamined, assigning soluble concentrations for all the events that are estimated from the above soluble reactions, the effect would be as follows:

1) Criteria exceedances for lead and cadmium are essentially eliminated. There are no exceedances in the streams, and for the land runoff they are reduced to only 1 for lead (versus 24), and 1 for cadmium (versus 13).

2) For zinc, the criteria exceedances that were observed only for streams S1 and S2 are reduced from 7 to 1. In the runoff, the number of exceedances is reduced (12 versus 25), but remains significant.

3) For copper, using the dissolved concentration for comparison reduces the criteria exceedances of runoff samples from land use stations, but the number remains significant at 15 or 16 (versus 21 using total concentrations). In the stream stations, exceedances are

significantly reduced, producing 3 or 4 compared with the 21 obtained using total concentrations, but the frequency remains significant.

6.5 TOC AND SYNTHETIC ORGANICS

The results of the chemical analyses for TOC and synthetic organic compounds in water samples collected from stream, reservoir, and land use stations are summarized in Tables 6-10 to 6-11 (a to e), compared and interpreted in this section. These organic analyses include:

- Total organic carbon, TOC (EPA 415.1)
- Total organic halogen, TOX (EPA 9020)
- Volatile organics (EPA 624)
- Semi-volatile organics (EPA 625)
- Polynuclear aromatic hydrocarbons, PAH (EPA 610)
- Organochlorine pesticides (EPA 608)
- Chlorinated herbicides (EPA 8150)
- Organophosphorus pesticides (EPA 8140)

Of these eight analytical methods, two of them, TOC and TOX, are screening methods for organic compounds. Both screening methods are relatively easy to perform, less costly than the other compound-specific methods, and generally provide useful information.

The TOC method measures a wide range of organic hydrocarbons, including natural (such as humic acids) and man-made compounds. The TOX method, however, is more specific and measures only organic compounds that are halogenated, i.e., compounds having chloride, iodide, or fluoride groups. Since halogenated compounds are predominantly man-made, analysis of water samples by the TOX method provides a useful indication of the extent of organic contribution from anthropogenic activities.

Table 6-10 Average TOC Values for Landuse, Stream, and Reservoir Stations

STATION	LANDUSE TYPE	TOC (mg/L)	
		WET	DRY
L1	INDUSTRIAL PARK	68	NS
L2	HEAVY INDUSTRY	14	NS
L3	COMMERCIAL/ RESIDENTIAL	11	NS
L4	RESIDENTIAL	9	NS
L5	COMMERCIAL/ RESIDENTIAL	12	NS
L6	RESIDENTIAL	12	NS
L7	OPEN	5*	NS
S1	STREAM	12	4*
S2	STREAM	13	4*
S3	STREAM	12	3*
S4	STREAM	10	11+
R1-R6	RESERVOIR	NS	5*

* TOC Value considered as natural background

+ The average TOC concentration is 5 mg/L if the 5/11/88 TOC value of 28 mg/L is considered an outlier

NS Not Sampled

Table 6-11 (a). Summary of TOX Detections in Landuse and Stream Stations

WET WEATHER			DRY WEATHER		
1. Detections by Stations					
STATIONS	DETECTIONS	NO. SAMPLES	STATIONS	DETECTIONS	NO. SAMPLES
S1	3	5	S1	4	4
S2	3	5	S2	0	4
S3	1	6	S3	1	5
S4	3	4	S4	3	4
L1	4	5			
L2	2	4			
L3	2	5			
L4	2	2			
L5	3	5			
L6	2	3			
L7	0	4			
R1-R6	0	1			
TOTALS	25	49	TOTALS	8	17
2. Detections by Individual Organic Compounds					
	NUMBER OF DETECTIONS	RANGE OF DETECTED CONCENTRATION (ug/L)		NUMBER OF DETECTIONS	RANGE OF DETECTED CONCENTRATION (ug/L)
TOX	25	28 - 100	TOX	8	30 - 120

Table 6-11 (b). Summary of Organochlorine Pesticide Detections in Landuse and Stream Stations

WET WEATHER			DRY WEATHER		
1. Detections by Stations					
STATIONS	DETECTIONS	NO. SAMPLES	STATIONS	DETECTIONS	NO. SAMPLES
S1	0	5	S1	0	6
S2	2	5	S2	0	6
S3	1	4	S3	0	7
S4	2	4	S4	0	7
L1	2	5			
L2	1	4			
L3	2	5			
L4	0	4			
L5	2	5			
L6	2	4			
L7	0	4			
R1-R6	0	1			
TOTALS	14	50	TOTALS	0	26

2. Detections by Individual Organic Compounds

	NUMBER OF DETECTIONS	RANGE OF DETECTED CONCENTRATION (ug/L)
DDE	6	0.074 - 0.10
DDT	5	0.05 - 0.25
ALPHA - BHC	4	0.05 - 0.077
GAMMA - BHC	3	0.032 - 0.18
GAMMA - CHLORDANE	3	0.1 - 0.2
TOTAL PCB	3	1.3 - 1.4
ALPHA - CHLORDANE	2	0.1 - 0.3
DDD	1	0.13
ENDOSULFAN - ALPHA	1	0.13
ENDOSULFAN - BETA	1	0.06
ENDOSULFAN - SULFATE	1	0.12

Table 6-11 (c). Summary of Chlorinated Herbicide Detections in Landuse and Stream Stations

WET WEATHER			DRY WEATHER		
1. Detections by Stations					
STATIONS	DETECTIONS	NO. SAMPLES	STATIONS	DETECTIONS	NO. SAMPLES
S1	0	1	S1	1	4
S2	0	1	S2	0	4
S3	0	2	S3	0	5
S4	0	2	S4	2	5
L1	0	2			
L2	0	2			
L3	0	2			
L4	0	0			
L5	0	1			
L6	0	2			
L7	0	1			
R1-R6	0	1			
TOTALS	0	17	TOTALS	3	18
2. Detections by Individual Organic Compounds					
				NUMBER OF DETECTIONS	RANGE OF DETECTED CONCENTRATION (ug/L)
			2, 4 - D	3	6.5 - 59.0
			DICAMBA	2	5.0 - 47.5

Table 6-11 (d). Summary of Volatile Organic Detections in Landuse and Stream Stations

1. Detections by Stations

WET WEATHER			DRY WEATHER		
STATIONS	DETECTIONS	NO. SAMPLES	STATIONS	DETECTIONS	NO. SAMPLES
S1	0	1	S1	0	1
S2	0	2	S2	1	1
S3	0	2	S3	0	1
S4	0	2	S4	0	1
L1	2	2			
L2	1	2			
L3	0	2			
L4	0	0			
L5	0	1			
L6	0	2			
L7	0	1			
R1-R6	0	1			
TOTALS	5	18	TOTALS	1	4

2. Detections by Individual Organic Compounds

WET WEATHER			DRY WEATHER		
	NUMBER OF DETECTIONS	RANGE OF DETECTED CONCENTRATION (ug/L)		NUMBER OF DETECTION	RANGE OF DETECTED CONCENTRATION (ug/L)
TOTAL XYLENE	2	9, 55	TCE	1	6
METHYLENE CHLORIDE	1	54			
ACETONE	1	30			
2-BUTANONE	1	130			

Table 6-11 (e). Summary of Polynuclear Aromatic Hydrocarbon Detections in Landuse and Stream Stations

1. Detections by Stations

WET WEATHER			DRY WEATHER		
STATIONS	DETECTIONS	NO. SAMPLES	STATIONS	DETECTIONS	NO. SAMPLES
S1	4	5	S1	0	6
S2	2	6	S2	0	6
S3	1	5	S3	0	7
S4	0	5	S4	1	7
L1	3	5			
L2	0	4			
L3	0	5			
L4	0	2			
L5	4	5			
L6	0	3			
L7	0	4			
R1 - R6	0	1			
TOTALS	14	50	TOTALS	1	26

2. Detections by Individual Organic Compounds

WET WEATHER			DRY WEATHER		
	NUMBER OF DETECTIONS	RANGE OF DETECTED CONCENTRATION (ug/L)		NUMBER OF DETECTIONS	RANGE OF DETECTED CONCENTRATION (ug/L)
BENZO (b) FLUORANTHENE	12	0.089 - 0.82	BENZO (b) FLUORANTHENE	1	0.083
BENZO (k) FLUORANTHENE	6	0.041 - 0.37	BENZO (k) FLUORANTHENE	1	0.04
FLUORANTHENE	6	0.26 - 3.3	BENZO (a) PYRENE	1	0.11
BENZO (a) PYRENE	4	0.081 - 1.0			
PYRENE	2	0.33 - 2.2			
INDENO (1,2,3 - cd) PYRENE	1	1.3			
BENZO (a) ANTHRACENE	1	0.58			

The other analytical methods measure specific organic compounds encompassing a wide spectrum of chemicals that are grouped by EPA as priority pollutants. These chemicals include commonly used solvents in industry (TCE, xylene), highly persistent organochlorine pesticides (DDT, chlordane), readily degradable organophosphorus pesticides, and polynuclear aromatic hydrocarbons.

6.5.1 Land Use and Reservoir Stations

Table 6-10 shows the results of the average TOC values detected in water samples collected from the land use stations (L1 to L7) during the wet weather, and all reservoir stations (R1 to R6). Table 6-11a to 6-11e provides a summary of all organic compounds that were found above the detection limits. This summary of organic detections is grouped under the different analytical methods and also provides frequency of detections for the sample monitoring period.

6.5.1.1 Results of Screening Analyses, TOC and TOX.

Open Areas. In the open areas, where there is no urban or industrial development, average TOC concentrations of 5 mg/L were detected in water samples collected from station L7 and all reservoir stations (Table 6-10). This TOC concentration of 5 mg/L can be considered to represent natural background organic carbon level in the Santa Clara Valley watershed.

Table 6-11a presents the results of another organic screening analyses, TOX. The TOX results showed that there were no detectable total halogenated compounds in samples from the open areas, L7, and the reservoir stations (R1-R6). The detection limit for all TOX analyses was consistently 25 μg/L and is considered an acceptable detection limit for this EPA-validated method. The non-detectable TOX results from these un-urbanized areas thus lend support to the earlier finding that the low TOC levels (5 mg/L) represent natural background conditions.

Urban Areas. In contrast to the background TOC level, average TOC concentrations were about a factor of two higher in samples from urbanized areas (Table 6-10). These urbanized areas include L2 (14 mg/L), L3 (11 mg/L), L4 (9 mg/L), L5 (12 mg/L), and L6 (12 mg/L). The highest average TOC concentration (68 mg/L) was detected in samples collected from station L1, where the land use type is classified as an industrial park. Note that storms 5 (February 9, 1989) and 6 (March 2, 1989) in station L1 contained elevated TOC concentrations of 44 and 260 mg/L, respectively. The higher TOC concentrations in the urbanized areas likely represents organic hydrocarbons contributed from anthropogenic sources.

As with the TOC concentrations, detectable TOX levels, indicating presence of anthropogenic halogenated compounds, were found in stations L1 to L6 (Table 6-11a). TOX concentrations ranged from 33 to 65 µg/L.

TOX concentrations detected in samples from mixed commercial/residential (L3 and L5) and residential areas (L4 and L6) were similar to those detected from samples collected from the industrial area (L2). The TOX concentrations ranged from 33 to 51 µg/L.

In contrast, the largest number of detectable TOX (i.e., four TOX detects out of five storm sample events) and also the highest TOX concentrations (50-65 µg/L) were found in samples from station L1. It is important to note that samples from station L1 also had the highest TOC concentration.

Summary. Therefore, based on TOC and TOX results, samples from station L1 showed the highest amount of organic concentrations that are potentially from anthropogenic sources. Samples from other urbanized areas, L2 to L6, contained relatively low levels of organics that are above the natural background organic concentrations found in open, undeveloped areas. Generally, the results of additional analyses for specific organic compounds in these land use and reservoir stations support the above observations. The following section discusses the results of these additional analyses in detail.

6.5.1.2 Results of Specific Synthetic Organic Analyses.

Open Areas. The results of additional analyses for specific synthetic organic compounds using EPA methods 624 (volatile organics), 608 (organochlorine pesticides), 610 (PAH), and 8150 (chlorinated herbicides) are summarized in Tables 6-11b to 6-11e. The results of analyses of water samples collected from open areas (L7 and reservoir stations) revealed that no detectable synthetic organic compounds were found. The absence of any priority pollutant organics confirm the earlier finding that the surface waters from the open areas are pristine and contain only natural levels of organic hydrocarbons.

Industrial Park Station, L1. Samples from L1 had the most number of detectable organics. These organic detections include organochlorine pesticides (Table 6-11b), a volatile organic (Table 6-11d), and PAH compounds (Table 6-11e). It is important to stress that although samples from station L1 had the most detectable organics of all the land use stations, these detections are relatively low concentrations and not consistently found in all the sampling events.

The organochlorine pesticides, endosulfan sulfate (0.12 µg/L) and alpha-BHC (0.077 µg/L), were detected only once on April 20, 1988 (storm event 1) and November 23, 1988 (storm event 2), respectively (Table 6-11b).

The first two wet-weather storms also produced detectable amounts of a volatile organic, xylene, at 9.0 and 5 µg/L (Table 6-11d). Xylene is a common solvent used in industry and is also a component of gasoline.

Polynuclear aromatic hydrocarbons (PAH) such as benzo(b)fluoranthene, benzo(k)fluoranthene, fluoranthene, benzo(a)pyrene, pyrene, indeno(1,2,3-cd)pyrene, and benzo(a)anthracene were commonly detected in three out of five storm samples (Table 6-11e). The storms in which these PAHs were detected were the later wet-weather storms--February 4, 1988; February 9, 1988; and March 2, 1989. The concentrations of these PAHs ranged from 0.041 to 1.3 μg/L. Although PAH compounds were not detected in the earlier February and November 1988 storm samples, their presence may be masked by higher detection limits (less than 10 μg/L) using method 625 for semi-volatile analysis. Subsequent analysis of PAH compounds by method 610 achieved better detection limits ranging from 0.02 to 2.0 μg/L.

Heavy Industrial Station, L2. The organic compounds detected in samples from the heavy industrial station L2 were volatile organics 2-butanone (130 μg/L), acetone (30 μg/L), and xylene (55 μg/L), and an organochlorine pesticide, DDT (0.16 μg/L). Of the four wet-weather samples collected, these compounds were detected only once in samples collected from the November 23, 1988, storm (Table 6-11b, d).

The presence of acetone is suspect because this compound was detected in laboratory method blanks. The other volatile organics are also commonly used solvents in the laboratory for extraction of samples. As such, the one-time detections of these volatile organics are uncertain and probably due to laboratory artifacts.

In contrast to numerous detections of PAH in samples from station L1, no PAH compound was detected in any L2 samples.

Mixed Residential/Commercial Stations (L3 to L6). In contrast to the industrial land use stations L1 and L2, no volatile organics were detected in any of the mixed residential/commercial or residential areas, L3 to L6 (Table 6-11d).

In the residential station (L4), no organochlorine or PAH compounds were detected (Table 6-11b, c).

Some organochlorine pesticides (alpha- and gamma-BHC, alpha- and gamma-chlordane, DDT, DDE, and PCB) were detected in samples from land use stations L3, L5, and L6 (Table 6-11b). Again, these detections were at low levels (less than 1.4 μg/L) and not consistently found in all sampling events.

Except for samples from L5, no PAH compounds were detected in land use stations L3, L4, and L6 (Table 6-11e). PAH compounds detected from L5, a mixed commercial/residential land use area, were present in four out of five storms sampled. Three PAH compounds, benzo(b)fluoranthene, benzo(k)-fluoranthene, and fluoranthene, were found. Recall that these three PAH compounds were also commonly detected in samples from the industrial area, L1.

A semi-volatile organic compound, bis(2-ethylhexyl)phthalate (BEHP) was found in a sample (April 20, 1988) at 41 μg/L. This compound was also detected at similar levels in samples from stations L2 (49 μg/L) and L6 (43 μg/L). BEHP was also detected at 11 to 800 μg/L in numerous laboratory blank samples. BEHP is commonly found in plastics such as tubing and gloves. The current guidance from EPA on evaluation of phthalate data (EPA 1988) notes that phthalates are common laboratory contaminants at levels of less than 100 μg/L. Based on evidence of BEHP contamination in the laboratory and EPA's current position on phthalate compounds, the detections of BEHP in samples from L1, L2, and L6 are therefore suspect and likely not found.

6.5.2 Stream Stations

This section discusses the results of TOC and synthetic organic compounds in stream samples from stations S1 to S4. The results are summarized in Tables 6-10 and 6-11a to 6-11e.

6.5.2.1 Results of Screening Analyses, TOC and TOX. Average TOC concentrations obtained in samples from the four stream stations during the wet-weather period showed levels that were similar to TOC levels from urbanized areas, L2 to L6 (Table 6-10). The average TOC concentrations in the stream stations ranged from 10 to 13 mg/L. These TOC levels found in the stream samples are not surprising since a major portion of the runoff is contributed from urbanized areas.

Samples taken in the dry-weather period, however, revealed lower TOC concentrations. Three stream stations, S1, S2, and S3, showed average TOC concentrations of 4, 4, and 3 mg/L, respectively. Except for a TOC concentration of 28 mg/L in a May 11, 1988, dry-weather sample from S4, the average TOC concentration based on three other dry-weather sampling events was 5 mg/L. These lower TOC levels detected in the dry weather are similar to the background TOC levels found in the open areas (L7 and reservoir stations).

It is likely, therefore, that the higher TOC concentrations detected in the wet-weather season for the four stream stations represent runoff from anthropogenic sources, whereas TOC levels in the dry season are probably reflective of natural organic concentrations.

During the wet-weather season, sporadic TOX concentrations were found above the detection limit in samples from all stream stations (Table 6-11a). Only one TOX detection (40 μg/L) out of six storm samples were found in stream station S3 (Guadalupe). In samples from stations S1, S2, and S4, three TOX detections out of four to five storm samples were found. All the above-mentioned TOX detections were at low levels and ranged from 28 to 50 μg/L, with the exception of a TOX concentration of 100 μg/L detected in a January 23, 1989, sample from station S1.

During the dry-weather period, relatively higher TOX concentrations ranging from 90 to 120 μg/L were detected in all four samples from station S1. The first TOX detection (February 26, 1988) was associated with detectable amounts of chlorinated herbicides. For the second TOX detection of 120 μg/L, however, no organochlorine or chlorinated compounds were detected. In subsequent dry-weather S1 samples, no organochlorine compounds were found. Except for the first dry-weather sample (February 26, 1988), both volatile and semi-volatile organic analyses were not performed on subsequent dry-weather samples. The detection of relatively high TOX concentrations in the dry-weather samples suggests that halogenated compounds may be present.

Samples from station S4 had three TOX detections out of five dry-weather samples, but the TOX concentrations were at low levels, 30 to 50 μg/L (Table 6-11a). As in station S1, chlorinated herbicides were detected in the first two dry-weather samples (February 26 and May 11, 1988), but not in the later dry-weather samples.

6.5.2.2 Results of Specific Synthetic Organic Analyses. Results of organic detections according to each specific analyses are presented in Tables 6-11b to 6-11e.

Synthetic organic compounds detected in samples from all stream stations were sporadic, at low levels of less than 1.4 μg/L, and predominantly found during the wet-weather period. Except for two chlorinated herbicide detections, no other organic compounds were detected during the dry-weather period.

The synthetic organic compounds detected during the wet-weather period were also very similar to those detected in samples from the land use stations. Most of the organic compounds such as organochlorine pesticides and PAH compounds are hydrophobic (i.e., relatively water insoluble) and strongly sorbed to sediments. Besides urban runoff that transports some of these organic pollutants to the streams, resuspension of stream sediments during large storm events potentially contributes a substantial amount of organics to the water phase. Sediment samples collected from these stream stations have consistently detected organochlorine and PAH compounds (Section 6.7 discusses the sediment quality in detail). As a result, the sediments serve as a potential source of organochlorine and PAH organics for stream runoff during the wet-weather period.

The organochlorine compounds such as alpha- and gamma-BHC, alpha- and gamma-chlordane, DDT and metabolites (DDD and DDE), endosulfan-I, endosulfan-II, and PCB were detected sporadically in one or two wet-weather samples from stream stations S2, S3, and S4 (Table 6-5b). No organochlorine compounds were detected in samples from station S1 during the wet-weather season.

However, PAH compounds, benzo(b)fluoranthene and benzo(a)pyrene, similar to those detected in samples from land use station L5 were detected in four out of five wet-weather samples from station S1 (Table 6-11e).

Other incidences of PAH detections during the wet-weather season include a one-time detection of fluoranthene and pyrene in station S3, and two PAH detections [benzo(k)fluoranthene, benzo(b)fluoranthene, fluoranthene, and benzo(a)pyrene] out of six sampling events in samples from station S2.

No chlorinated herbicides were detected in any of the wet-weather samples from all stream stations (Table 6-11c).

The only synthetic organic compounds detected during the dry-weather season were chlorinated herbicides (Table 6-11c) and a trace level of a volatile organic, TCE (trichloroethane). TCE was found at 6.0 μg/L in a February 26, 1988, sample from station S2. This TCE concentration is only slightly above the detection limit of 5.0 μg/L.

Both chlorinated herbicides, 2,4-D (13.0 μg/L) and dicamba (5.0 μg/L) were detected in a dry-weather sample (February 26, 1988) from station S1. In dry-weather samples from station S4, the compound 2,4-D (6.5 μg/L) was detected once on February 26, 1988, and again at 59.0 μg/L on May 11, 1988. Dicamba was also detected at 47.5 μg/L in the latter dry-weather sample from station S4. The occurrence of these two chlorinated herbicides only during the dry-weather period suggests that the source of these organic compounds is not related to urban runoff. Specific applications of 2,4-D and dicamba may have occurred in the vicinity of stations S1 and S4 to control aquatic weeds or related weed problems during the dry-weather periods.

6.5.2.3 Comparison with Toxic Criteria. As with the case of trace metals, the main concern with synthetic organics in storm runoff is their potential toxicity to aquatic organisms. The EPA toxic criteria for organics that is currently available is limited and consists of only a few organochlorine organic compounds such as DDT (and metabolites), chlordane, PCB, and dicamba.

Table 6-12 lists the EPA criteria for the organochlorine compounds, for both acute (short-term exposure) and chronic (extended exposure) effects on freshwater aquatic life. Because of the limited number of organic compounds for which EPA criteria are available, comparisons of monitoring data with these EPA criteria are restricted only to the organochlorine compounds.

For the wet-weather monitoring data, none of the observed concentrations of chlordane (alpha or gamma), DDT, and DDE exceeded the acute toxic criteria for these compounds. Concentrations of DDT and DDE runoff samples from stream and land use stations were about an order of magnitude lower than the acute concentration of 2.4 μg/L. Chlordane concentrations were approximately three to four times lower than the acute criteria of 1.1 μg/L.

Table 6-12. **Water Quality Criteria for Organochlorine Compounds**

Constituent	Units	Chronic	Acute
Chlordane	µg/L	0.0043	2.4
DDT, DDD, DDE	µg/L	0.001	1.1
PCBs	µg/L	0.014	NA
Dicamba	µg/L	NA	200

NA Criteria Not Available

The chlorinated herbicide, dicamba (<0.3 to <5 μg/L), was not detected in any of the wet-weather monitoring samples from either land use or stream stations. During the dry-weather period, however, dicamba was observed in a February 26, 1988, sample from S1 (5.0 μg/L) and S4 (47.5 μg/L). Chronic level for dicamba is not available, but these dicamba levels are below the acute concentration of 200 μg/L.

For the dry-weather period, concentrations of chlordane, DDT, DDE, and PCBs were below the method detection limit. However, the chronic criteria levels for these compounds are extremely conservative and at least 100 times lower than the reported detection limits in this study. As such, no valid comparisons could be made for these levels of organochlorine compounds during the dry-weather period.

6.6 BACTERIA

This section summarizes the data obtained on concentrations of coliform bacteria at the land use and stream monitoring sites. These pollutants are not significant for the assessment of the toxicity issues. For the Study Area, their significance is related to potential human health effects associated with recreational water contact activities or shellfish harvesting.

Microorganisms are naturally present in soil and water. Their growth and death rates are influenced by a variety of factors, including temperature and sunlight. The levels present can also be influenced by anthropogenic factors. For example, sanitary sewage has high concentrations of bacteria. The coliform group has long been used as a general indicator of bacterial quality. Organisms measured in the test for "total" coliform bacteria include the naturally occurring soil and water forms. The "fecal" group includes organisms that are present in the enteric systems of warm-blooded animals. Harmless in themselves, fecal coliforms have historically been used as indicators of contamination by sewage, signalling the potential presence of harmful pathogenic organisms.

Fecal coliforms are routinely encountered in urban runoff and stream samples that are known to be uncontaminated by sewage, and under circumstances that make it unlikely that their presence is attributable to domestic pets and wildlife. The monitoring results presented should therefore be interpreted principally as measures of the biological quality of the different sources.

All of the monitoring results for total and fecal coliform are listed in Table 6-13 for the land use sites, and in Table 6-14 for the stream stations. The wide variability indicated for each of the individual data sets should not be attributed solely to event-to-event differences in quality. The analytical test is not precise and could be a significant component of the observed variability.

Geometric mean concentrations are listed for each of the sampling sites, to provide a general indication of the differences in measured values. The overall variability, combined with the limited number of samples for an individual site, suggest caution in attributing the differences shown to actual site effects.

A comparison of the pooled data from the five residential/commercial land use sites, and from the four stream stations during wet and dry weather, is provided by Figures 6-9 (total coliform) and 6-10 (fecal coliform). The lognormal fits for the larger sets provided by the use of pooled data are good, and because all individual sites in a grouping exhibited individual values at both high and low ends of the range, the groupings employed are reasonable for a general comparison. This suggests that the group geometric means (which correspond to the median for lognormal distributions) are reasonable estimates of central tendency for the category.

TABLE 6-13. Coliform Bacteria for Land Use Stations

Sample Site	Date		Samp Event	COLIFORM BACTERIA (MPN/100ml)		GEOMETRIC MEAN (MPN/100ml)	
	Mo	Day		Total	Fecal	Total	Fecal
RESIDENTIAL / COMMERCIAL LAND USE STATIONS							
L1	4	20	1	2,300	2,300	23,000	3,300
L1	11	23	2	110,000	24,000		
L1	2	9	5	110,000	15,000		
L1	3	2	6	9,300	150		
L3	4	20	1	350,000	7,900	45,000	4,400
L3	11	23	2	46,000	11,000		
L3	2	9	5	11,000	4,600		
L3	3	2	6	24,000	930		
L4	4	20	1	24,000	4,900	38,000	7,500
L4	11	23	2	> 240,000	110,000		
L4	2	9	5	24,000	2,400		
L4	3	2	6	15,000	2,400		
L5	4	20	1	170,000	4,900	33,000	1,900
L5	11	23	2	4,600	400		
L5	1	23	3	24,000	2,400		
L5	2	9	5	46,000	2,400		
L5	3	2	6	46,000	2,400		
L6	4	20	1	70,000	500	24,000	1,300
L6	11	23	2	46,000	1,500		
L6	2	9	5	46,000	15,000		
L6	3	2	6	2,100	240		
OPEN LAND USE STATION							
L7	4	20	1	17,000	800	19,000	500
L7	11	23	2	110,000	11,000		
L7	2	9	5	750	75		
L7	3	2	6	93	93		
INDUSTRIAL LAND USE STATION							
L2	4	20	1	7,900	2,300	6,000	1,000
L2	11	23	2	4,600	2,400		
L2	2	9	5	4,600	2,400		
L2	3	2	6	7,500	93		
SANTA CLARA RESERVOIR STATIONS							
R1	2	27	1	8	< 2	14	5
R2	2	26	1	49	33		
R3	2	27	1	2	< 2		
R4	2	27	1	8	5		
R5	2	27	1	540	13		
R6	2	27	1	2	< 2		

Table 6-14. Coliform Bacteria for Stream Stations

Sample Site	Date Mo	Date Day	Samp Event	COLIFORM BACTERIA (MPN/100ml) Total	COLIFORM BACTERIA (MPN/100ml) Fecal	GEOMETRIC MEAN (MPN/100ml) Total	GEOMETRIC MEAN (MPN/100ml) Fecal
STREAM STATIONS - DRY WEATHER							
S1	2	26	1	2,400	2,400	9,500	1,200
S1	3	30	2	4,900	2,300		
S1	5	11	3	130,000	8,000		
S1	12	12	5	-	-		
S1	2	1	6	4,600	43		
S1	4	6	7	11,000	1,500		
S2	2	26	1	35,000	4,600	8,100	900
S2	3	30	2	1,300	1,300		
S2	5	11	3	30,000	2,000		
S2	12	12	5	-	-		
S2	2	1	6	11,000	93		
S2	4	6	7	2,400	460		
S3	2	26	1	5,400	2,400	12,400	600
S3	3	30	2	7,900	4,900		
S3	5	11	3	110,000	2,000		
S3	8	22	4	-	70		
S3	12	12	5	-	780		
S3	2	1	6	17,500	33		
S3	4	6	7	3,500	780		
S4	2	26	1	2,400	920	19,000	700
S4	3	30	2	24,000	24,000		
S4	5	11	3	900,000	4,000		
S4	8	22	4	-	70		
S4	12	12	5	-	43		
S4	2	1	6	4,600	93		
S4	4	6	7	11,000	2,400		
STREAM STATIONS - WET WEATHER							
S1	4	20	1	350,000	3,300	174,000	32,000
S1	11	23	2	>240,000	110,000		
S1	2	9	5	>240,000	125,500		
S1	3	2	6	46,000	24,000		
S2	4	20	1	54,000	7,000	64,000	16,000
S2	11	23	2	>240,000	< 240,000		
S2	1	23	3	24,000	11,000		
S2	2	9	5	240,000	11,000		
S2	3	2	6	15,000	4,600		
S3	4	20	1	240,000	17,000	69,000	21,000
S3	11	23	2	>240,000	< 240,000		
S3	1	23	3	24,000	4,600		
S3	2	9	5	24,000	4,600		
S3	3	2	6	46,000	46,000		
S4	4	20	1	54,000	17,000	130,000	59,000
S4	11	23	2	>240,000	110,000		
S4	1	23	3	>240,000	> 240,000		
S4	2	9	5	110,000	15,000		
S4	3	2	6	110,000	110,000		

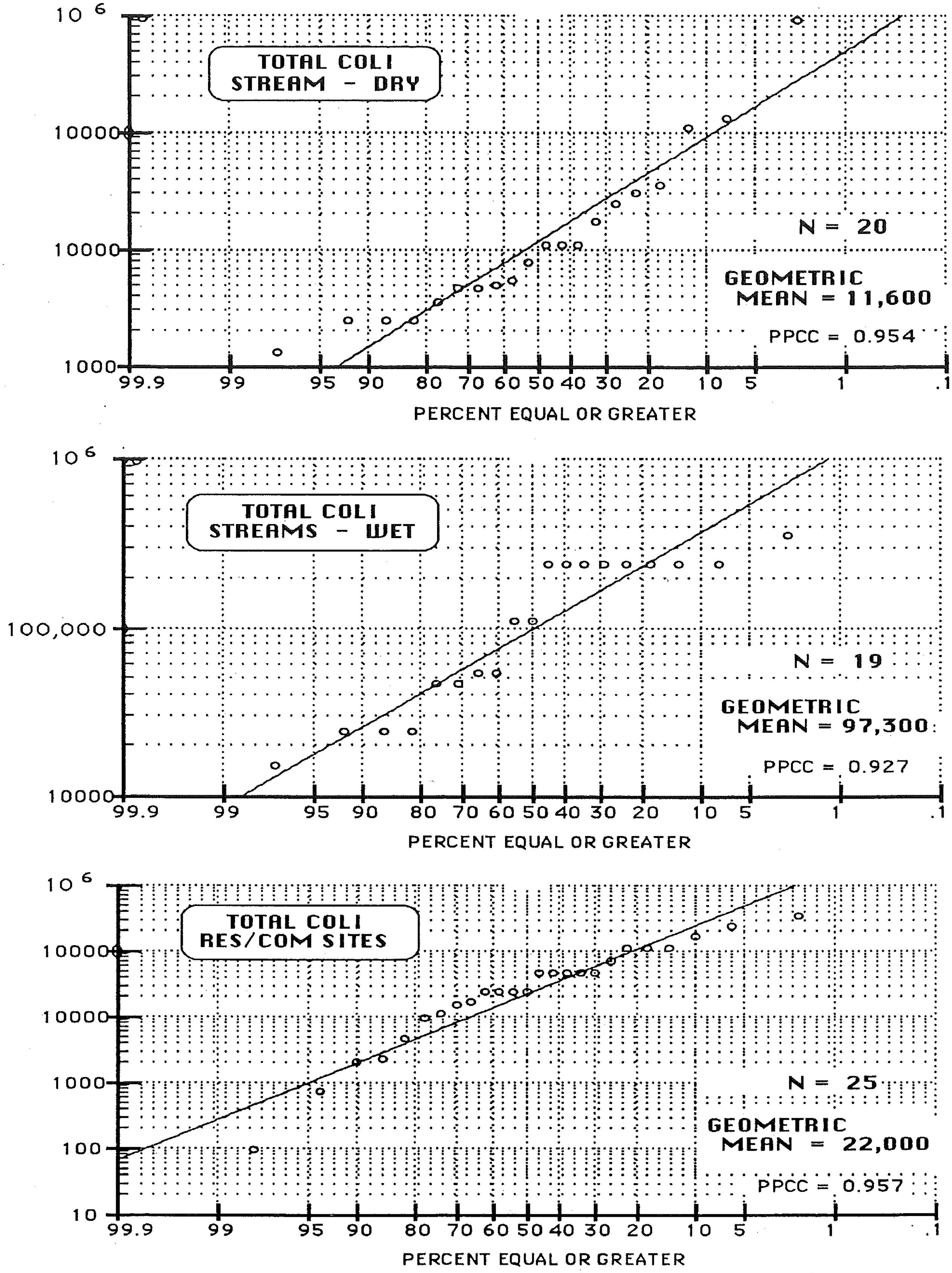


Figure 6-9. Total Coliform Bacteria Concentrations Grouped by Site Type.

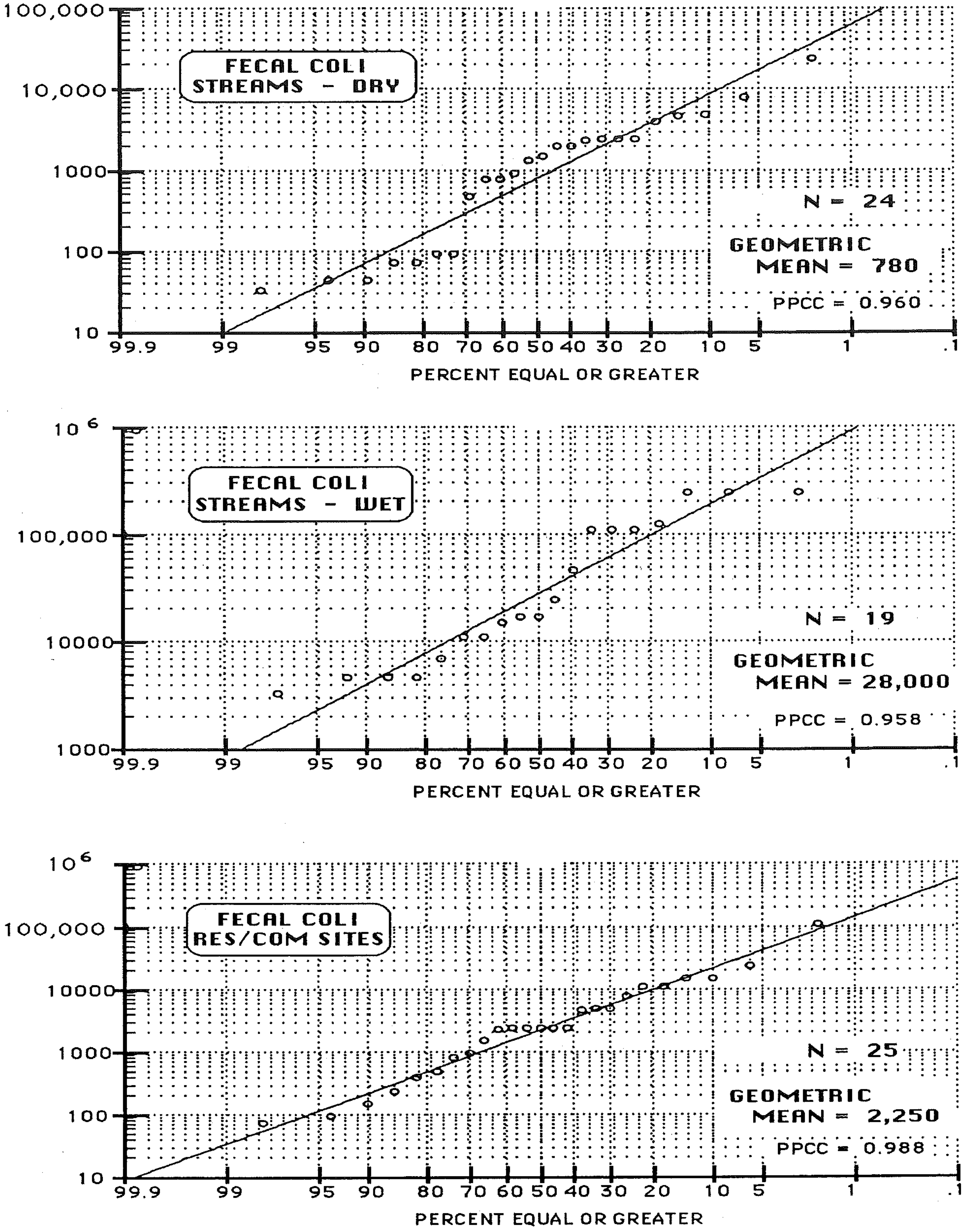


Figure 6-10. Fecal Coliform Bacteria Concentrations Grouped by Site Type.

The results indicate that stream total coliform levels are about eight times higher during wet weather than during dry periods. Total coliform levels in runoff from the land sites is about double the dry-weather stream concentrations, but only about one-quarter of the wet-weather levels.

In the case of fecal coliform, the pattern is similar. Stormwater runoff concentrations from the land sites are again about twice as high as the dry-weather stream levels. However, for fecal coliform bacteria, the difference between the runoff and the wet-weather stream concentrations is even greater, the ratio here being about a factor of 10.

The industrial and open land use sites were not included in the grouping, but inspection of Table 6-13 indicates concentrations to be comparable to the residential/commercial sites that were grouped. It is therefore reasonable to expect that the comparison is applicable for runoff from the overall watershed.

6.7 SEDIMENT QUALITY

This section summarizes the results of chemical analyses for metals and organics in sediment samples at the four stream stations. Four sediment samples were collected during the dry-weather period encompassing the period from March 1988 to December 1988. Sediments that contain clay and/or organic carbon content play an important role as both a source or sink for metals and hydrophobic organic pollutants. Because of the sediment sorptive capacity for such constituents, sediments may act as a sink for pollutants released into the stream water. Conversely, the pollutant-rich sediments can also serve as a source during high streamflows in the wet-weather season when the sediment material (particularly the fine silt and clay fraction) is resuspended into the water phase.

6.7.1 Metals

The metal results are presented in Table 6-15. Of the 10 metals, 5 of them (zinc, chromium, copper, nickel, and lead) have concentrations that were consistently above 50 mg/kg (ppm). The other 5 metals (arsenic, cadmium, mercury, selenium, and silver) were about an order of magnitude lower in concentrations, and also have values that were below the detection limits. The following two sections discuss the distribution of these metals according to the high- and low-concentration categories. Metal concentrations are also compared to the USGS sediment data base, and natural background concentrations.

6.7.1.1 Zinc, Chromium, Copper, Nickel, and Lead. Based on the mean concentrations, Table 6-15 shows that these five metals (zinc, chromium, copper, nickel, and lead) were consistently detected at the highest concentrations in sediment samples from stream station S3 (Guadalupe). The mean concentrations of these five metals are followed in decreasing order by station S4 (Coyote), S2 (Sunnyvale East Channel), and S1 (Calabazas). Among the five metals, zinc concentrations were the highest (ranging from 100.5-211.0 mg/kg), followed in decreasing order by chromium (81.0-125.0 mg/kg), nickel (62.3-20.2 mg/kg), copper (34.5-69.3 mg/kg), and lead (28.5-99.6 mg/kg).

A summary of the sediment metal quality obtained from the USGS database is shown in Table 6-16 for two stations, Guadalupe (USGS station no. 11169000) and Coyote (USGS station no. 11171500). The USGS Guadalupe station is at the same location as station S3 in this study; the USGS Coyote station is located about 10 miles upstream of station S4. The mean and range of concentrations represent sediment data from the period 1979 to 1988. The metals zinc, chromium, copper, and lead were among the highest concentrations observed. This observation is consistent with the sediment data obtained in this study. For the Coyote station, consistently high detection limits of 100 mg/kg for nickel precluded any analysis of the nickel data; nickel analysis was not performed for samples from the

Table 6-15. Mean Metal Concentration (mg/kg) and Grain Size Distribution of Sediment Samples from Stream Stations

STATION	% Silt	%Clay	Zinc	Chromium	Copper	Nickel	Lead	Mercury	Selenium	Silver	Arsenic	Cadmium
S3	64.3	9.3	211	125	69	120	100	3.1	0.9*	1.2*	5.4	0.8
S4	26.0	6.9	167	90	50	116	58	0.3	0.5	1.0*	7.3	0.7
S2	11.4	1.1	115	81	49	64	66	0.1*	1.4*	1.0*	3.6	1.3
S1	9.3	0.0	101	78	35	62	29	0.1*	0.2*	0.6*	4.1	0.1
NO. SAMPLES PER STATION			4	2	4	3	4	4	4	4	2	2
NATURAL SOILS†			50 10 - 300	100 1 - 1,000	30 2 - 100	40 5 - 500	10 2 - 200	0.03 0.01 - 0.3	0.30 0.1 - 2	0.05 0.01 - 5	5 1 - 50	0.06 0.01 - 0.70

* At least one value was below the detection limit.
The value at the detection limit was used to calculate the mean

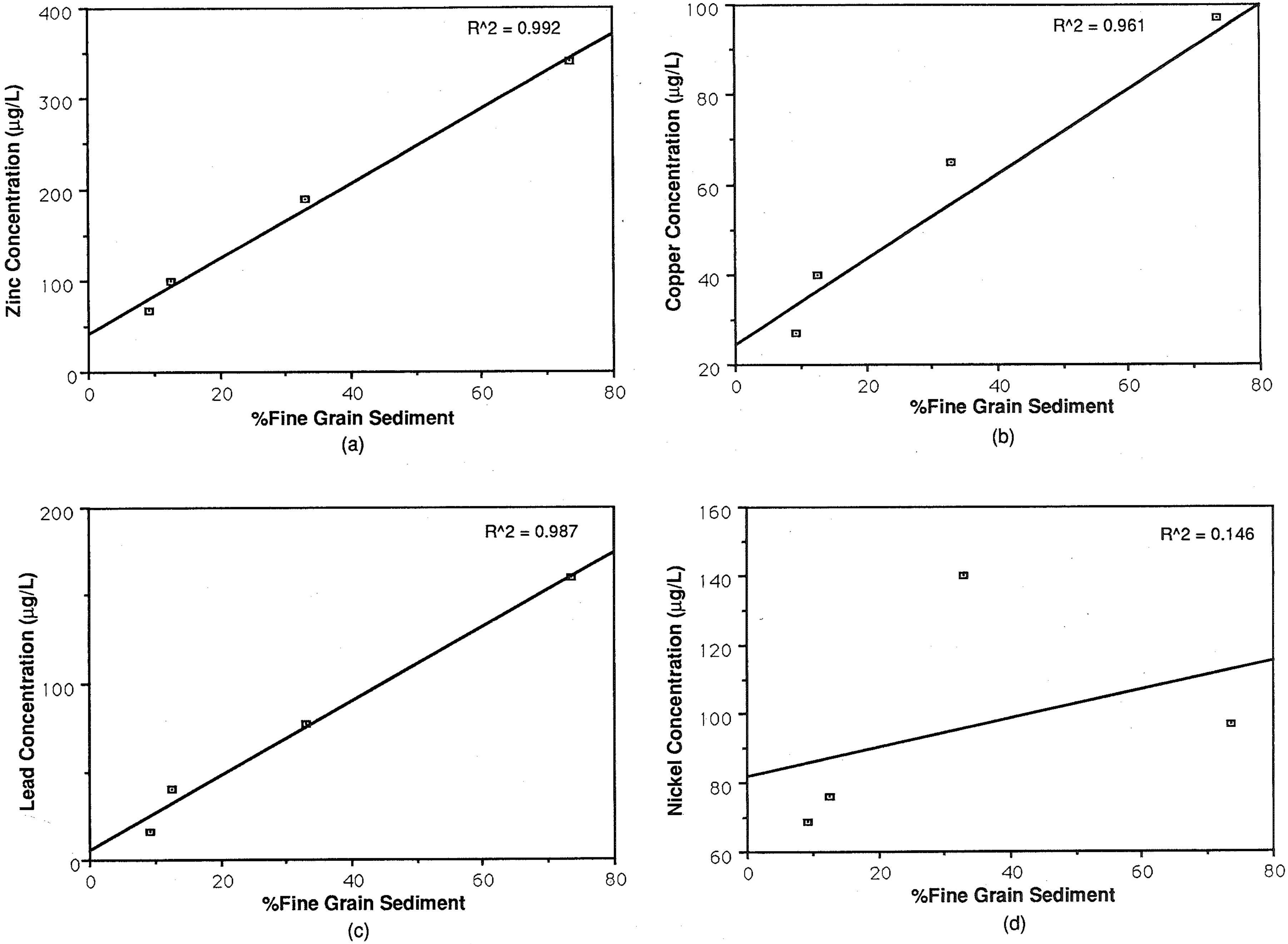
† Lindsay, WL. 1979. Chemical Equilibria in Soils. Numbers Reported are Means and Ranges

Guadalupe station. As a general comparison, the range of concentrations reported for sediment samples obtained in this study (based on four sediment samples) were clearly within the range of concentrations reported in the USGS sediment database.

Since metals tend to be associated with sediments, correlations between metal concentrations and other sediment properties such as grain size distribution were investigated. Figure 6-11 (a-d) illustrates the graphs obtained from plotting the metal concentrations versus the amount of fine-grain-size sediment. The amount of fine-grain-size material from the sediment sample was obtained by summing the silt and clay fractions. Two sediment samples were obtained on August 22 and December 12, 1988. The correlations shown in the graphs were performed on the sediment and chemical data from the August 22, 1988, samples. For the three metals (zinc, copper, and lead) as shown in Figure 6-11 (a, b, c), the amount of silt and clay in the stream sediment was highly correlated with these metal concentrations. For the case of nickel (Figure 6-11d), however, there was a poor correlation. This means that the higher concentrations of zinc, copper, and lead observed in sediment samples from station S3 can be mostly explained by the larger proportions of fine sediment material (silt and clay) present.

During high-streamflow events, the sediment material (especially the finer sediment fractions) is rapidly mixed with the stream runoff. This is evidenced by high total suspended solids or turbidity concentrations observed for storm samples collected in the wet-weather period. Accordingly, the water quality data for stream samples showed the highest concentrations for zinc, copper, chromium, nickel, and lead--the same metal constituents that were detected at the highest concentrations in the sediment samples.

6.7.1.2 Arsenic, Cadmium, Mercury, Selenium, and Silver. This second group of metals were detected at levels of less than 10 mg/kg (Table 6-15), with numerous results reported below the detection limit.



(a)

(b)

(c)

(d)

Figure 6-11. Relationship Between Metal Concentration and Percent Fine Grain Sediment

The average mercury concentration in sediment samples was highest at station S3. The mean mercury concentration (3.1 mg/kg) was at least 10 times higher than mercury levels observed in other stations. The source of the mercury levels in S3 sediment samples is most likely from past mining activities in the Guadalupe watershed.

In comparisons with detectable concentrations of arsenic, cadmium, mercury, selenium, and silver in stream water samples, the concentrations in water samples of these five metals were also reported at low levels with numerous concentrations below the detection limit (see Section 6.4).

The USGS sediment data (Table 6-16) for this group of metals generally reported concentrations that were similar to the concentrations observed in this study.

6.7.1.3 Comparison with Natural Background Metal Concentrations. Determination of background metals concentrations in sediments can be made very generally by using metals data collected from (1) an upstream USGS Coyote Station (No. 11171500) as a background location, and (2) natural soils as cited in literature.

Using zinc, chromium, and copper as examples, the mean concentrations from the USGS station were lower by about two to five times the concentrations from the downstream station S4. However, as demonstrated in the earlier discussion, the relative amounts of silt and clay in the sediments have a significant effect on metals accumulation. In fact, the USGS particle size distribution data showed only about 5 percent silt and 3 percent clay in contrast with a much larger value of 26 percent silt and 7 percent clay in station S4. Therefore, preliminary analysis showing higher concentrations of zinc, chromium, and copper may likely be attributable to higher accumulation of silt and clay at this location. Given the significant role of silt and clay in accumulation of metals in

Table 6-16. Mean and Range of Metal Concentrations of USGS Sediment Samples from Guadalupe and Coyote Stations

METAL	CHROMIUM	COPPER	LEAD	ZINC	ARSENIC	CADMIUM	SELENIUM	MERCURY
1. GUADALUPE STATION								
MEAN (mg/kg)	103	52	157	154	6.3	NC	NC	1.9
RANGE (mg/kg)	10 - 740	20 - 180	20 - 1000	70 - 810	1 - 16	<1 - 2	<1 - 3	0.03 - 3.5
2. COYOTE STATION								
MEAN (mg/kg)	65	11	81	65	7	NC	NC	0.21
RANGE (mg/kg)	10 - 160	4 - 20	20 - 210	30 - 100	3 - 10	< 1 - 1	<1	0.05 - 1.0

NC Mean Not Calculated Because of Numerous Values Reported Below the Detection Limit sediments, it is difficult to evaluate whether the fine sediments were contributed from upstream background locations, stormwater runoff, or runoff from potential illegal dumping locations in the adjacent area.

Based on metal concentrations of natural soils reported in the literature (Lindsay 1979) and summarized in Table 6-15, the ranges of metal concentrations found in all stream stations appear to be well within the ranges of natural levels.

6.7.2 TOC and Synthetic Organics

The organic analyses performed on sediment samples were similar to those for the water samples (as discussed in Section 6.5) with the exception that there is no TOX analysis for solid samples.

6.7.2.1 TOC. Sediment samples collected on March 30, 1989, were analyzed for TOC content. The highest TOC concentration, expressed as a percent level, was found in sediment samples from S3 (3.4 percent), followed in decreasing order by S2 (1.7 percent), S4 (1.1 percent), and S1 (less than 0.01 percent). These TOC concentrations are much larger (except for S1 sediment) than those found in the water phase because of the organic fraction present mostly as natural humic materials. This large amount of natural organic content in the sediment potentially serves as a sorbent for trace synthetic organic compounds.

6.7.2.2 Organochlorine Pesticides. Organic compounds that were commonly observed in all four sediment samples were the extremely persistent organochlorine pesticides. Table 6-17 summarizes the results of the positive detections for organochlorine compounds.

The organochlorine pesticides that were commonly detected include DDT (6.4 to 37 μg/kg) and degradation by-products, DDD (2 to 34 μg/kg) and DDE (2.4 to 26 μg/kg), alpha-chlordane (8 to 28 μg/kg) and gamma-chlordane (6 to 20 μg/kg), gamma-BHC (5 to 7.8 μg/kg), beta-endosulfan (3.4 to 9 μg/kg), and PCBs (140 to 183 μg/kg).

Table 6-17. Summary of Organochlorine Pesticide and Polynuclear Aromatic Hydrocarbon Detections in Sediments

ORGANOCHLORINE PESTICIDES

1. Detections by Stations

STATIONS	DETECTIONS	NO. SAMPLES
S1	4	4
S2	4	4
S3	4	4
S4	4	4
TOTALS	16	16

2. Detections by Individual Organic Compounds

	NUMBER OF DETECTIONS	RANGE OF DETECTED CONCENTRATION (µg/kg)
DDE	11	2.4 - 26
ALPHA - CHLORDANE	9	8 - 28
DDD	9	2 - 34
DDT	9	6.4 - 37
GAMMA - CHLORDANE	8	6 - 20
PCB	4	140 - 183
GAMMA - BHC	2	5, 7.8
ENDOSULFAN - BETA	2	3.4, 9

POLYNUCLEAR AROMATIC HYDROCARBONS

STATIONS	DETECTIONS	NO. SAMPLES
S1	1	4
S2	1	4
S3	3	4
S4	2	4
TOTALS	7	16

	NUMBER OF DETECTIONS	RANGE OF DETECTED CONCENTRATION (µg/kg)
BENZO (b) FLUORANTHENE	4	190-540
BENZO (k) FLUORANTHENE	4	100-270
BENZO (a) ANTHRACENE	4	100-270
BENZO (a) PYRENE	4	200-490
FLUORANTHENE	4	400-910
PYRENE	4	350-570
PHENANTHRENE	3	260-380

Concentrations of these organochlorine pesticides seem to be higher in sediment samples from station S3 (Guadalupe). Since hydrophobic organic compounds (i.e., relatively water-insoluble organics) are sorbed strongly to the organic fraction of sediments, the higher concentration may be attributable to the larger amount of total organic carbon content (3.4 percent) found in S3 sediments. These same organochlorine compounds were also observed in stream water samples during the wet-weather period. As in the metal-sediment association (zinc, lead, copper), the pesticide-laden sediment is a potential source of pesticide loading to the storm water runoff.

6.7.2.3 Polynuclear Aromatic Hydrocarbons. In addition, polynuclear aromatic compounds were also detected in at least three out of four sampling events. Table 6-17 summarizes the results of the positive detections for PAH compounds.

The commonly detected PAH compounds include benzo(b)fluoranthene (190 to 40 μg/kg), benzo(k)fluoranthene (100 to 270 μg/kg), benzo(a)anthracene (100 to 270 μg/kg), benzo(a)pyrene (200 to 490 μg/kg), fluoranthene (400 to 910 μg/kg), pyrene (350 to 570 μg/kg), and phenanthrene (260 to 380 μg/kg). About 85 percent of the 27 detections were observed in the last dry-weather sample of December 12, 1988 (Table 6-17). The large number of PAH detections observed in the last dry-weather sample are most likely due to a change to a more sensitive HPLC analysis (method 8310) for PAH compounds. Results of PAH analysis using this HPLC method typically reports detection limits that are about 10 times lower than those obtained by the earlier GC analysis (method 8270 for semi-volatiles) performed on the first three sediment samples.

With the exception of phenanthrene, these detectable PAH compounds were also detected in the water samples (as discussed in Section 6.5).

6.7.2.4 Non-Detectable and Suspect Organic Detections. No chlorinated herbicides or organophosphorus pesticide compounds were detected.

For volatile organics, a one-time detection (March 30, 1988) of a trace level of toluene (5 µg/kg) and acetone (63 µg/kg) was reported in a sediment sample from station S3. The detections of these two volatile organics are highly uncertain and suspect because of the following reasons: (1) the method blank was contaminated with 27 µg/kg of acetone, (2) the concentration of toluene was found at the detection limit of 5 µg/kg and (3) none of these compounds were detected in another sample (May 11, 1988) collected from station S3, nor in other samples from stations S1, S2, and S4.

As in the water samples, the detection of a semi-volatile compound, bis(2-ethylhexyl)phthalate (BEHP), is likely from laboratory contamination and/or due to the ubiquitous presence of BEHP in the environment. BEHP was detected once in sediment samples from S4 (May 11, 1988) and twice in samples collected from S3 (March 30 and May 11, 1988). The BEHP concentration was reported at 2900 µg/kg in the S4 sample, and at 2700 and 970 µg/kg in S3 samples. A related phthalate compound, butylbenzylphthalate, was also detected at 490 µg/kg in a sediment sample from S3 (March 30, 1988). Method blanks from the laboratory also reported levels of BEHP at 800 to 2400 µg/kg.

SECTION 7

7.0
TOXICITY RESULTS

The results of the toxicity tests on stream and land use stations are summarized and discussed in this section. An effect is considered to have occurred when a measured parameter in a group exposed to water from a sampling station is significantly different from controls, either because the difference was obvious (i.e., no survivors or offspring) or because statistical tests indicated that the probability of no difference was less or equal to 0.05.

7.1 METHODOLOGY

The toxicity testing program was designed to be a screening-level study to determine if toxicity occurred in either storm runoff or streams receiving storm runoff. The program was conducted during both dry- and wet-weather conditions. Three rounds of dry-weather testing were conducted on the four stream stations. Wet-weather toxicity testing was conducted at 11 sites (S1 through S4, L1 through L7) during three storm events.

The program employed tests utilizing Ceriodaphnia dubia (an aquatic invertebrate), Pimephales promelas (a fathead minnow fish), and Selenastrum capricornutum (a freshwater alga). Tests conducted with these species followed the general guidelines provided by EPA (Horning and Weber 1985) on short-term methods for estimating chronic toxicity in freshwater. These tests are not designed to estimate acute toxicity. However, organisms that died within the first day or two after test initiation may indicate acute toxicity. Future reference to toxicity in the following sections pertains to chronic toxicity, and cases where acute effects are shown will be specifically stated as acute toxicity.

Several modifications were made to EPA's standard test protocol. Since the study was intended only to be a screening-level program, tests were not run using the standard dilution series. Only 100 percent test water was utilized in all cases. Another modification to the standard test protocol was a reduction in exposure volumes in the *Pimephales* test from 500 ml to 250 ml per container. This latter modification was incorporated to allow the bioassay water to be subsampled from the composite samplers during storm events. Chemistry performed on the storm composites could then be used to aid interpretation of the bioassay water.

The approach to static-renewal of test waters differed between the dry- and wet-weather toxicity testing. Test water was obtained on a daily basis from each of the stream stations during dry-weather testing. The first day of water collection was coordinated with collection of water samples for dry-weather water quality surveys in order to provide some chemistry support. During each daily water collection, sufficient water was obtained to complete the full test in the event of interruption by an unanticipated storm event. During wet-weather toxicity testing, all test water was obtained from the ISCO composite samplers. This required that the sampling rate of the automatic samplers be roughly doubled in order to collect the additional 7 liters necessary to perform the full suite of test procedures. Since this additional volume could not be consistently obtained, it was often necessary to run reduced suites for the chemical analysis.

7.2 DRY-WEATHER CONDITIONS

Table 7-1 summarizes the results of all of the toxicity tests on water samples collected during dry-weather conditions.

Table 7-1. Summary of Results of Toxicity Tests on Dry Weather Samples.

CERIODAPHNIA				FATHEAD MINNOW				SELENASTRUM		
TEST NO.	TREAT. GROUP	SURV. (%)	NO. OF YOUNG	TEST NO.	TREAT. GROUP	SURV. (%)	MEAN WEIGHT (mg)	TEST NO.	TREAT. GROUP	CELL DENSITY**
1	Control	100	126	1	Control	100	0.4067	1	Control	1.998
	S-1	100	149		S-1	97	0.4037		S-1	3.483
	S-2	100	183		S-2	83	0.3606		S-2	4.125
	S-3	100	169		S-3	97	0.4022		S-3	2.780
	S-4	100	125		S-4	90	0.3428*		S-4	2.025
2	Control	100	178	2	Control	93	0.4147	2	Control	2.620
	S-1	100	351		S-1	97	0.3537		S-1	2.580
	S-2	30*	27*		S-2	87	0.3923		S-2	5.170
	S-2A	100	240		S-2A	Not tested			S-2A	3.730
	S-3	100	278		S-3	83	0.4220		S-3	3.300
	S-4	100	297		S-4	90	0.4477		S-4	2.130
3	Control	100	177	3	Control	97	0.5200	3	Control	3.080
	S-1	90	275		S-1	97	0.4833		S-1	3.230
	S-2	80	150		S-2	97	0.5100		S-2	3.730
	S-3	100	277		S-3	97	0.4400*		S-3	2.990
	S-4	10*	170		S-4	100	0.4500		S-4	1.420*

* Significantly lower than controls ($p \leq 0.05$).

** Million cells/ml.

7.2.1 Effects on Ceriodaphnia

Water collected from the S2 station (Sunnyvale East Channel) had an effect on survival and offspring production in Ceriodaphnia in the second set of tests, but had no effect on the measured parameters in the first and third set of tests. Only 30 percent of the daphnids exposed to the water survived during the 7-day exposure period, compared with 100 percent survival in the control group. The surviving daphnids produced a total of 27 young compared with 178 young produced by the control group. This effect was not corroborated by the duplicate sample S2A, in which no effects were detected.

In the third set of tests, water collected from the S4 station (Coyote Creek) had an effect on survival of Ceriodaphnia, but no effect on offspring production. Only 10 percent of the daphnids survived during the 7-day exposure period. None of the controls died. Daphnids exposed to water from station S4 produced 170 young, which is only 7 less than the daphnids in the control group did. Daphnids exposed to the S4 water during the first and second sets of tests were not affected.

7.2.2 Effects on Fathead Minnows

In the first set of tests, fathead minnow larvae exposed to water from station S4 (Coyote Creek) were affected: they were 15.7 percent lighter in weight than controls after the 7-day exposure period. Water from the creek had no effect on larval survival. Water from stations S1, S2, and S3 had no effect on larval survival or weight.

In the second set of tests, water from stations S1 through S4, including a duplicate water sample (S2A) from station S2, had no effect on any of the measured biological parameters. In the third set of tests, water from station S3 (Guadalupe River, San Jose) affected weight gain. At the end of the 7-day exposure period, larvae exposed to water from the river were 15.4 percent lighter than larvae in the control group. Water samples from the other stations had no effect on larval survival or weight.

7.2.3 Effect on Selenastrum

Water from station S4 affected cell density in Test No. 3, where cell density was 46 percent of control cell density. Water from all of the other stations had no effect on Selenastrum cell density.

7.3 WET-WEATHER CONDITIONS

Table 7-2 summarizes the results of all of the toxicity tests on water samples collected during wet-weather conditions.

7.3.1 Effects on Ceriodaphnia

Water from all of the stream and land use stations except L7 (which samples an undeveloped area in the Santa Cruz Mountains) affected survival in at least one of the three tests performed. Water from S1, S2, and S3 and from L3, L4, L5, and L6 killed all of the test animals every time they were tested (most water samples were tested three times, others were tested once or twice). Water from L2 was tested twice. In one test (Test 1), none of the animals survived. In the other test (Test 3), the number surviving was the same as controls, but they produced less than half the number of offspring as the controls did (80 vs 156). No offspring were produced by groups in which none of the initial animals survived. In the two tests conducted on water from L1, 80 percent of the initial animals survived in one test (Test 1) and none survived in the other test (Test 3). The number that survived was not statistically different from the number of control survivors (100 percent); however, the survivors did not reproduce. Most of the tests that exhibited toxicity, with the exception of S2 (Test 2) and L4 (Test 2), showed that the Ceriodaphnia died within the first day of test initiation. These results suggest that the stormwaters are acutely toxic to Ceriodaphnia.

Table 7-2. Summary Results of Toxicity Tests on Wet Weather Samples

CERIODAPHNIA

Test No.	Treat. Group	Surv. (%)	No. Of Young
1	Control	100	230
	S - 1	0+	0
	S - 2	0+	0
	S - 3	0+	0
	L - 1	80	0
	L - 2	0+	0
	L - 3	0+	0
	L - 4	0+	0
	L - 5	0+	0
	L - 6	0+	0
	L - 7	100	295
2	Control	100	173
	S - 1	0+	0
	S - 2	0	0
	S - 3	Not tested	--
	S - 4	Not tested	--
	L - 1	0+	0
	L - 2	Not tested	--
	L - 3	0+	0
	L - 4	0	0
	L - 5	0+	0
	L - 6	0+	0
	L - 7	100	258
3	Control	90	156
	S - 1	0+	0
	S - 2	0+	0
	S - 3	Not tested	--
	S - 4	0+	0
	L - 1	Not tested	--
	L - 2	90	80
	L - 3	0+	0
	L - 4	0+	0
	L - 5	0+	0
	L - 6	0+	0
	L - 7	100	179

FATHEAD MINNOWS

Test No.	Treat. Group	Surv. (%)	Mean Weight (mg)
1	Control	93	0.541
	S - 1	97	0.357*
	S - 2	100	0.420*
	S - 3	Not tested	--
	S - 4	Not tested	--
	L - 1	0+	0.000
	L - 2	0+	0.000
	L - 3	Not tested	- -
	L - 4	97	0.541
	L - 5	100	0.410*
	L - 6	Not tested	--
	L - 7	97	0.470
2	Control	100	0.257
	S - 1	100	0.367
	S - 2	97	0.291
	S - 3	Not tested	--
	S - 4	Not tested	--
	L - 1	0+	0.000
	L - 2	Not tested	--
	L - 3	Not tested	--
	L - 4	Not tested	--
	L - 5	100	0.353
	L - 6	Not tested	--
	L - 7	90	0.421
3	Control	100	0.406
	S - 1	97	0.263*
	S - 2	97	0.273*
	S - 3	Not tested	--
	S - 4	Not tested	--
	L - 1	Not tested	--
	L - 2	90	0.175*
	L - 3	97	0.255*
	L - 4	Not tested	--
	L - 5	97	0.265*
	L - 6	93	0.258*
	L - 7	100	0.332*

SELENASTRUM

Test No.	Treat. Group	Cell Density**
1 - 1	Control	3.24
	L - 3	3.35
	L - 4	3.25
	L - 5	1.22*
	L - 6	2.44*
	L - 7	2.15*
1 - 2	Control	3.68
	S - 1	3.80
	S - 2	2.83
	S - 3	3.81
	L - 1	0.038*
	L - 2	0.0061*
2 - 1	Control	2.53
	S - 1	1.98*
	S - 2	1.78*
	S - 3	1.98*
	S - 4	1.86*
	L - 1	0.00
2 - 2	Control	1.91
	L - 3	2.14
	L - 4	0.48*
	L - 5	1.04*
	L - 6	2.82
	L - 7	2.12
3 - 1	Control	2.46
	L - 4	1.56*
	L - 5	1.06*
	L - 6	0.011*
	L - 7	2.17*
3 - 2	Control	2.92
	S - 1	2.55
	S - 2	2.42
	S - 4	1.23*
	L - 2	1.15*
	L - 3	4.03

* Significantly lower than controls ($p \leq 0.05$)

** Million cells/ml.

+ Organisms died within the first day of test initiation suggesting acute toxicity.

7.3.2 Effects on Fathead Minnows

With minnows, tests were conducted on water from stations S1, S2, and S3 and L1, L4, L5, L6, and L7. Water from S1 and S2 and L5 and L7 was collected and tested three times. Water from L1 and L2 was collected and tested twice, and water from the rest of the stations was collected and tested once.

The only water that was toxic to minnows each time it was tested was from station L1. In both tests performed on the water, none of the minnows survived after 1 day, which therefore suggests acute toxicity effects. Water from S1 and S2 had no effect on minnow survival; however, in two of three tests, it had a negative effect on weight gain. In one test on water from station L2, none of the minnows survived after 1 day. This suggests acute toxicity similar to results from station L2. In the other test, 90 percent survived, but weight gain was affected. Water from L3, tested once, had not effect on minnow survival, but it reduced weight gain. Water from L4 had no effect on minnow survival or weight gain. Water from L5 had no effect on minnow survival in all three tests; however, in two of the tests, it caused a reduction in weight gain. Water from L6 had no effect on minnow survival in the only test performed on it; but it reduced weight gain. In the three tests performed on water from L7, no effect on survival was observed; however, in one of the tests it reduced weight gain.

7.3.3 Effects on Selenastrum

In the first set of tests, exposure to water from stations S1, S2, and S3 and L3 and L4 had no effect on Selenastrum cell density. Water from stations L1, L2, L5, L6, and L7 negatively affected cell density. In the second set of tests, water from L3, L6, and L7 had no effect on cell density; however, water from S1, S2, S3, and S4 and L1, L4, and L5 caused a reduction in cell density. In the third set of tests, water from stations S1 and S2 and L3 had no effect on cell density, but water from the other stations caused a statistically significant reduction in cell density.

7.4 DISCUSSION

The basic assumptions made in the selection of the test organisms is that (1) they are sensitive members of the taxonomic groups that they represent and (2) the groups to which they belong are present in the streams of concern. Thus, if any water sample from a stream or land use station is toxic to a test organism belonging to a group, it will most likely be toxic to organisms belonging to the same group inhabiting the stream.

7.4.1 Dry-Weather Samples

Results of the toxicity tests were not consistent from test to test. The toxicity tests showed that water from Calabazas Creek (S1) had no observable adverse effects on any of the tested species. In one of the tests on water from the Sunnyvale East Channel (S2), survival and offspring production in *Ceriodaphnia* was affected; however, water from the river had no effect on any of the tested species in the other two tests. Water from the Guadalupe river caused a reduction in weight gain in fathead minnow larvae in the second test, but had no effect on any of the tested species in the other tests. Water from Coyote Creek (S4) reduced weight gain in fathead minnow larvae in the first test and reduced survival in *Ceriodaphnia* and cell density in *Selenastrum* in the third test, but had no effect on any of the tested species in the second test.

The concentrations of metals found in water samples subjected to the toxicity tests were examined to determine if the toxicity of samples from the Sunnyvale East Channel (S2) and Coyote Creek (S4) might be related to known toxicological end points for the chemicals. These end points are shown in Table 7-3. Organic compounds found in the samples were examined and eliminated from further consideration because of the lack of pertinent toxicological end points for most of them and the inconsistency in their occurrence. The concentrations of the metals in the samples are shown in Table 7-4. The concentration of cadmium in the water sample from the

Table 7-3. Ambient Water Quality Criteria and Toxicity Estimates (μg/l)*

	ACUTE CRITERIA		CHRONIC CRITERIA		LOWEST LC50/EC50		LOAEL** CHRONIC EXPOSURE		
CHEMICAL	Max	1-Hour	24-hr	4-day	Cladocera	Minnow	Cladocera	Minnow	Algae
Arsenic	- -	360	- -	190	812	15660	912	- -	2320
Cadmium	- -	9W,30D	- -	2W, 5D	49	11000	0.21	37	50
Chromium(+3)	- -	3100W, 7533D	- -	370W, 898D	2000	5070	44		397
Chromium(+6)	NA	NA	NA	NA	NA	NA	NA	NA	NA
Copper	- -	9.2	- -	6.5	69	260	7.2	24	50
Lead	- -	200W,800D	- -	8W, 30D	1910	5E+05	85	70(BG)	500
Mercury	- -	2.4	- -	0.025	2.2	33(T)	1.1	0.26	100
Nickel	- -	2600W, 6500D	- -	280W, 720D	2410	25000	220	380	100
Selenium	- -	20	- -	5	430	620	70	83	50
Silver	1.2	- -	- -	- -	- -	- -	- -	- -	- -
Zinc	- -	47	- -	570W, 1286D	655	2610	42	48(Soft)	30

* Toxicity values shown are from tests with water hardnesses of at least 200 ppm when hardness affects toxicity.

** Lowest observed adverse effect level.

NA = Not applicable

W = wet weather hardness of 200 ppm

D = dry weather hardness of 600 ppm

T = trout

BG = bluegill

Table 7-4. Metal Concentrations in Dry Weather Samples Subjected to Toxicity Tests (μg/l)

	STATION AND TEST NUMBER														
	S-1			S-2			S-2A			S-3			S-4		
CHEMICAL	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Arsenic												1.0			2.0
Cadmium		0.3			0.4	0.6		0.2						0.6	
Chromium(+3)		1.0	1.0		2.0	3.0		3.0			3.0	2.0		4.0	3.0
Chromium(+6)															
Copper	7.0		6.0	6.0		3.0		4.0		3.0		4.0	3.0	1.0	6.0
Lead				1.2				4.0							
Mercury															
Nickel			2.0			3.0						2.0			5.0
Selenium				5.0		4.0		0.5		0.3	0.8			0.4	1.0
Silver				4.7		0.7						0.2			0.2
Zinc	12.0	14.0	6.0	7.5	28.0	10.0		10.0		26.0	7.0	10.0	10.0	12.0	20.0

Where no value is shown, concentration was below detection limits.

Sunnyvale East Channel exceeded the lowest reported concentration having an observable adverse effect (LOAEL) on cladocerans, a taxonomic group to which *Ceriodaphnia* belongs. The S4 sample used in the second test also contained a cadmium level that exceeded the LOAEL and the level of cadmium in the sample was higher than in any other sample except the S2 sample used in the third test. While this observation could be used to explain why *Ceriodaphnia* were adversely affected, it does not explain why *Ceriodaphnia* were not affected by the duplicate sample of S2 water used in the second test. Nor does it explain why water from S2 had no effect on *Ceriodaphnia* in the third test even though the level of cadmium in the water was the same as that in the S4 sample that had an effect. Examination of other chemicals found in the water samples failed to reveal any relationship between concentration and observed toxic effects.

7.4.2 Wet-Weather Samples

The results of the tests on water samples collected from stream and land use stations during storm events indicate that nonpoint source runoff in the streams and storm drains can be toxic. Water from most of the stream and land use stations was acutely toxic to *Ceriodaphnia* and water from some of the land use stations (L1 and L2) was acutely toxic to fathead minnows.

As with the dry-weather samples, the concentrations of metals identified in the water samples subjected to the toxicity tests were compared with toxicological endpoints presented in Table 7-3. The concentrations of the metals are shown in Tables 7-5 and 7-6. The exercise revealed that the toxicity of the samples does not appear to be related to the concentrations of the metals. The concentration of copper in all of the samples that were lethal to *Ceriodaphnia* exceeded the lowest published LC50 for cladocerans. Copper, trivalent chromium, and zinc concentrations also exceeded the acute criterion for ambient water quality in the lethal samples. However, several samples that were not lethal (S4, test 1; L1, test 1; and L2, test 3) were not lethal to *Ceriodaphnia* although copper,

Table 7-5. Metal Concentrations in Wet Weather Stream Samples Subjected to Toxicity Tests (µg/l)

	STATION AND TEST NUMBER											
	S-1			S-2			S-3			S-4		
CHEMICAL	1	2	3	1	2	3	1	2	3	1	2	3
Arsenic		3.0	4.0		3.0							8.0
Cadmium	3.5	1.1	1.3	3.5	1.4	1.5	1.9	3.5	0.7	3.5	1.2	4.0
Chromium (+3)	19.0	26.0	27.0	26.0	29.0	50.0	1.6	51.0	22.0	23.0	27.0	73.0
Chromium (+6)												
Copper	32.0	44.0	55.0	60.0	50.0	60.0	60.0	75.0	33.0	35.0	27.0	110.0
Lead	32.0	5.0	60.0	81.0	35.0	50.0	91.0	110.0	12.0	35.0	15.0	130.0
Mercury		0.2	0.2				0.4			35.0		
Nickel		100.0	90.0	18.0	120.0	90.0	84.0	110.0	80.0	35.0	120.0	150.0
Selenium		1.0							1.0		1.0	
Silver		0.2	0.2		0.3	0.4			0.4		0.3	2.0
Zinc	120.0	230.0	240.0	350.0	250.0	270.0	230.0	350.0	19.0	180.0	36.0	420.0

Where no value is shown, concentration was below detection limit.

Table 7-6 Metal Concentrations in Wet Weather Land Use Samples Subjected To Toxicity Tests (µg/l)

	STATION AND TEST NUMBER											
	L-1			L-2			L-3			L-4		
CHEMICAL	1	2	3	1	2	3	1	2	3	1	2	3
Arsenic						1						
Cadmium	4.0	1.4		5.2	9.5	4.7	3.5	1.2	1.3		1.7	0.6
Chromium(+3)	19.0	12.0		75	38	38	16	8	15		21	23
Chromium(+6)												
Copper	65.0	55.0		47	60	39	25	33	22		28	33
Lead	595.0	35.0		238	110	75	45	35	55		4	7
Mercury		0.2						0.2	0.2			
Nickel	18.0	450.0		35	80	80		30	40		18	60
Selenium											0.5	1
Silver	2.0	1.0		7	1	2			1		0.5	3
Zinc	350.0	400.0		1800	2000	700	180	260	320		88	20

	L-5			L-6			L-7		
	1	2	3	1	2	3	1	2	3
Arsenic					2	2		4	
Cadmium	3.5	1.3	1.1	3.5	1.5	1.4	1.7		0.2
Chromium(+3)	19	17	19	14	74	23	12	5	22
Chromium(+6)									
Copper	70	50	44	23	39	55	16	4	11
Lead	91	45	110	7	30	130		1	3
Mercury								0.2	
Nickel	18	60	60		110	70		6	90
Selenium								1	
Silver			0.2			0.2		0.2	0.3
Zinc	530	310	240	180	200	300		5	12

Where no value is shown, concentration was below detection limits.

trivalent chromium, and zinc concentrations in the samples were similar to the lethal ones. Zinc concentrations in all samples tested from station S1, S2, and S4 and L1, L2, L3, L5, and L6 exceeded the lowest concentration reported to be toxic to green algae; however, cell density in Selenastrum was not consistently affected by the samples. The concentration of all metals in the sample from station L7 did not exceed levels known to be toxic to green algae, yet Selenastrum cell density was affected in two of the three tests performed on samples from that station.

7.5 CONCLUSIONS

The results of tests conducted to estimate the toxicity of samples of water from stream and land use stations to aquatic life using Ceriodaphnia dubia (a cladoceran), Pimephales promelas (fathead minnow), and Selenastrum capricornutum (a green alga) as surrogates showed that during dry weather, water in selected streams is not toxic to aquatic life in 86 percent of the tests; only 14 percent of the tests showed toxicity. None of the dry-weather samples showed any acute toxicity. However, during wet weather, water from the same streams and from some land use areas that drain into the streams are frequently toxic. These storm waters were acutely toxic to Ceriodaphnia.

The toxicity of water collected during wet weather does not appear to be related to the concentration of heavy metals although the concentrations of several of the metals exceeded ambient water quality criteria for the protection of freshwater organisms as well as concentrations known to be lethal or cause chronic effects in the tested species or closely related species. It is possible that other unmeasured chemical agents or factors are involved.

The results of the toxicity tests indicate that runoff from urban areas can adversely affect biota under laboratory conditions and by extension in receiving streams. These results support urban runoff-related effects on biota in Coyote Creek reported by Pitt and Bozeman (1982) and discussed in Section 3.0.

SECTION 8

8.0
LOADS ANALYSIS

This section describes the procedures and results of the pollutant loads analysis. Specifically, Sections 8.2, 8.3, and 8.4 address the methodology used for the three components which constitute the total load, i.e., dry weather, wet-weather reservoir release, and wet-weather runoff, respectively. Loading results are given in Section 8.5. Section 8.6 discusses aspects relating to the reliability and uncertainty of annual load estimates. In Section 8.7, load estimates for nonpoint sources are compared with load estimates for the three wastewater treatment plants that discharge into the Lower South Bay.

8.1 INTRODUCTION

Water entering the Lower South Bay from tributary streams can be characterized in terms of the volume of water that has entered the Bay and the quality of that water. The product of the volume times a representative concentration is the load or total mass (pounds) of a given constituent entering the Bay. Thus, there is a hydrologic component and a water quality component that must be estimated in order to predict loads.

With regard to the hydrologic component, it is obviously important to take into account the variability in annual rainfall. To do this, we have made load estimates for the period 1977-1989 because this period had the most complete precipitation and streamflow data. The purpose of using this period is not to make historical predictions of loads, but to make predictions based on current conditions (e.g., current land use) for a range of hydrologic conditions. Ideally this period of record would be typical in terms of precipitation, and how the reservoirs and water supply system were managed. In fact this period of record includes the wettest year on record (1982-1983) and some of the drier years of record.

Based on the analysis of the hydrologic and water quality data, it was convenient to consider the total nonpoint source load to be the sum of:

- Wet-weather runoff load,
- Dry-weather load, and
- Wet-weather reservoir release load.

The wet-weather runoff load is the load associated with stormwater runoff from the area below the water-supply reservoirs. This is the major component of the total load and therefore was the focus of this study. The dry-weather load is the load associated with baseflow between winter storms and during the summer. The reservoir release loads are loads associated with managed releases or unmanaged spills (when the reservoir capacity is exceeded) that reach the Bay. This load is part of the wet-weather load, but we have chosen to distinguish between reservoir release loads and stormwater runoff loads to facilitate interpretation of results, particularly during wet years which had significant reservoir spills.

8.2 DRY-WEATHER LOADING METHODOLOGY

The dry-weather loads are the loads associated with winter baseflow between storms and summer baseflow. Based on an analysis of streamflow records for the period 1974-1988, it was determined that the total dry-weather flows consist of:

- Natural baseflow derived from groundwater discharging directly to the creeks,

- Managed releases into the stream associated with the operation of the SCVWD water supply system, and
- Discharge into the stream (or storm drain system) from NPDES-permitted discharges.

Information on the point source discharges operating under NPDES permits was provided by the Regional Board, and the relevant data are summarized in Appendix G. Based on the streamflow records, and the location of the permitted discharges, the sources of dry weather loads were identified for each of the watersheds, as shown in Table 8-1. Annual dry weather flows for the period of record (1974-1988) were then estimated using one of three methods, as noted in Table 8-1. Procedures employed for the alternate methods are described in Sections 8.2.1 through 8.2.3.

8.2.1 Method 1: Streams Where Permitted Discharges Could Be Identified

Figure 8-1 shows the measured annual dry-weather flows for Station S2, Sunnyvale East Channel, for the period 1977 through 1989 (1988-1989 is only through April). At the top of the figure the dry-weather flows are seen to increase dramatically starting in 1982-1983 in response to permitted discharges. The permitted discharge flows for 1986-1987 and 1987-1988 were assumed to be representative of current conditions and the mean volume based on these 2 years was used in estimating the contribution of this source to the total dry-weather flows for the period of record. This is justified as the purpose of using the period of record is not to make predictions of historical loads, but to make predictions of current loads for a range of meteorological conditions.

8.2.2 Method 2: Streams with Reservoir and Water Supply Releases

For watersheds which include reservoir and water supply releases, it was not possible to distinguish between releases and permitted discharges. In these cases, the actual flow record at the downstream gage was used to estimate the annual dry-weather flows.

Table 8-1. SOURCES OF DRY-WEATHER LOADS FOR EACH WATERSHED

Watershed	Permitted Discharges	Reservoir and Water Supply Releases	Natural Baseflow	Method Used to Estimate Dry-Weather Flows
Coyote Creek	•	•	•	2
Guadalupe River	•	•	•	2
San Tomas Aquinas Creek	•		•	1
Saratoga Creek		•	•	2
Calabazas Creek	•	•	•	2
Sunnyvale East Channel	•		•	1
Sunnyvale West Channel	•		•	3
Stevens Creek		•	•	2
Permanente Creek			•	3
Adobe-Matadero-Barron			•	3
San Francisquito Creek			•	3

Methods

1. For creeks with permitted discharges and natural baseflow only, assume dry-weather flow records (with allowance for natural baseflow) for 1986-1987 and 1987-1988 are good estimates of current permitted discharge flows. Estimate annual flows as sum of current permitted discharge flows and 2 percent of annual wet-weather flows.

2. For creeks which include reservoir and water supply releases, use actual flow record at downstream gage to estimate annual dry-weather flows.

3. For creeks with primarily natural baseflow, estimate annual dry-weather flow as 2 percent of annual wet-weather flow.

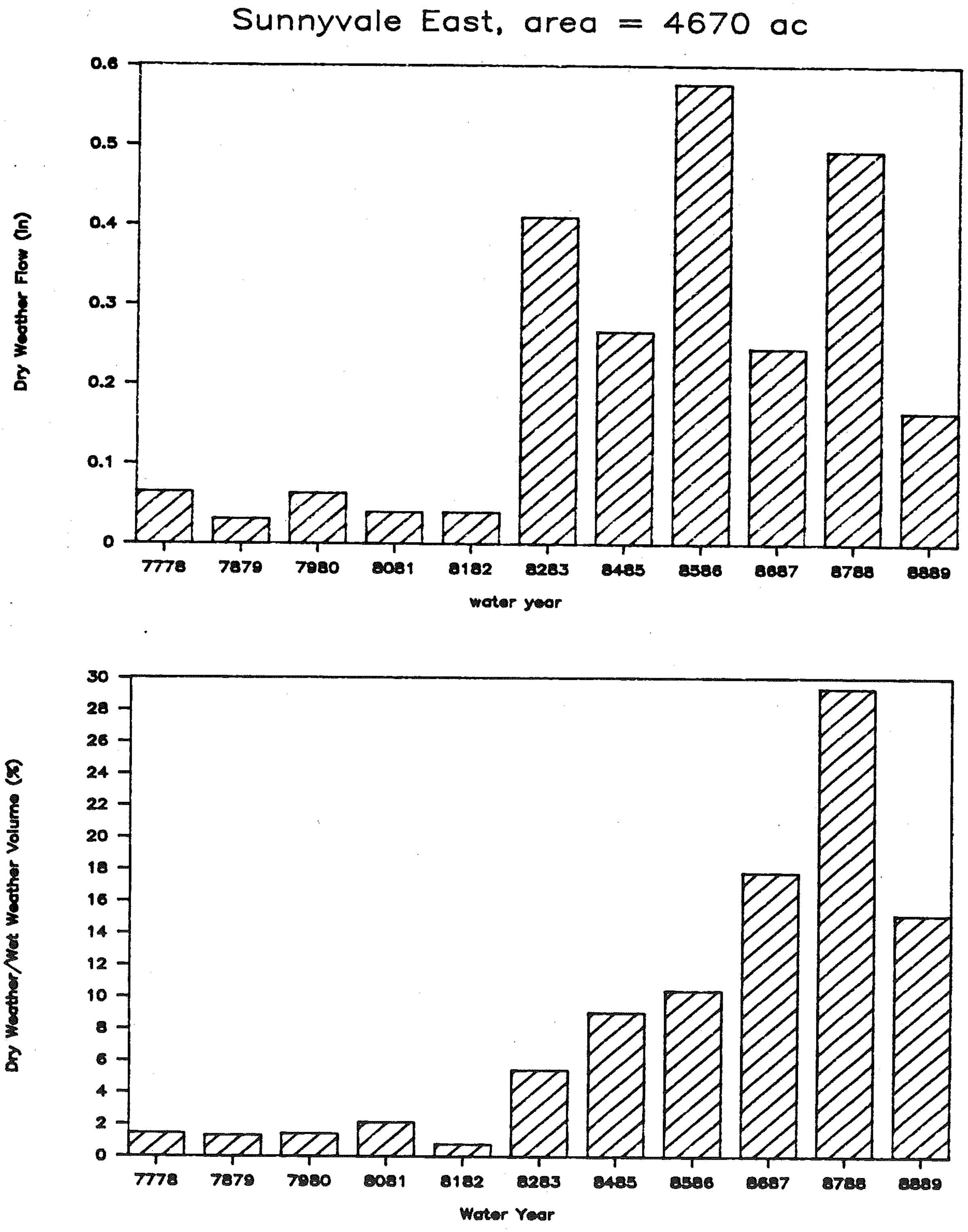


Figure 8-1. DRY WEATHER ANNUAL FLOWS AT STATION S2, SUNNYVALE EAST CHANNEL AT FREMONT (Values for 1988 - 89 include through April 1989 only)

8.2.3 Method 3: Streams with Primarily Natural Baseflow

Prior to 1982-1983 the dry-weather flows were of natural original and, as shown in the bottom of Figure 8-1, equaled about 2 percent of the annual wet-weather volumes. Similar results for the ratio of dry- to wet-weather flows were obtained at other stations. Thus, for the precision required in this analysis, it was adequate to estimate the natural baseflow as a fixed percentage of the wet-weather runoff. For streams in this category, dry-weather flows were estimated as 2 percent of the wet-weather flows. This method was utilized primarily at ungaged watersheds in which the wet-weather flows were predicted using the SWMM model.

Dry-weather loads were estimated as the product of the dry-weather volumes times the mean dry-weather concentrations for the lumped stream stations (Table 8-2).

8.3 WET-WEATHER RESERVOIR RELEASE LOADING METHODOLOGY

Wet-weather reservoir release loads are loads associated with managed releases or spillway releases. These loads are part of the wet-weather load; however, it is important to distinguish between the reservoir release loads and the downstream stormwater runoff loads to facilitate data interpretation and source identification. Such reservoir release loads are only important in a few of the watersheds and during wet years when reservoir storage capacity is exceeded.

Wet-weather reservoir releases were estimated by comparing the flow record at a station below a reservoir with that at the downstream gage. If the flow at the downstream gage exceeded the release flow measured at the gage below the reservoir, it was assumed that the release flow was not diverted but rather reached the Bay. This is consistent with the SCVWD policy that, during wet weather, flows are not diverted into recharge basins.

Table 8-2. MEAN CONCENTRATION OF RUNOFF FROM MONITORING STATIONS

LANDUSE TYPE	STATIONS	SEASON	N	Cadmium µg/L	Chromium µg/L	Copper µg/L	Lead µg/L	Nickel µg/L	ZINC µg/L	BOD mg/L	NO3-N mg/L	PO4-P mg/L	TKN mg/L	TSS mg/L
INDUSTRIAL	L2	WET	5	5.9	39.1	52.9	133.5	54.0	1471	13	0.6	0.7	1.8	152
RESIDENTIAL/ COMMERCIAL	L1,L3,L4, L5,L6	WET	25	1.7	21.1	50.5	60.8	40.9	251	10	0.7	0.3	2.1	76
OPEN	L7	WET	5	0.6	10.0	9.0	4.0	18.4	10	5	0.2	0.19	1.1	85
RESERVOIRS	R1 to R6	DRY	6	<0.2	7.0	6.0	2.0	8.0	10	-	0.2	<1	<1	24
STREAM	S1	WET	5	2.2	28.3	52.5	63.4	66.2	268	11	0.5	0.56	1.9	190
	S2	WET	7	2.3	41.7	69.1	64.5	51.8	337	17	0.5	0.90	2.1	234
	S3	WET	6	1.6	40.8	79.1	85.6	107.4	294	8	0.6	1.10	2.4	454
	S4	WET	6	3.2	45.2	65.6	82.0	98.5	263	11	0.9	0.73	1.5	248
STREAM	S1,S2, S3,S4	DRY	12	0.3	3.5	7.4	1.4	2.0	13	4	2.3	0.10	1.5	13

Note: Based on estimate of median and coefficient of variation as described in section 6.0

The loads were computed as the product of the estimated release flows times the mean concentration for the lumped reservoir stations (Table 8-2). This assumes that the water quality of the released water remains unchanged as it flows to the Bay. There are no data to verify this assumption; however, especially during wet years, this assumption seems reasonable given the short travel times and large volumes of water released.

8.4 WET-WEATHER RUNOFF LOADING METHODOLOGY

8.4.1 Objectives and Options

Prior to discussing the methodology, it is appropriate to list considerations and objectives that the wet-weather runoff loads analysis should meet.

- The time and space scales of the analysis must be such that annual loads from a large study area involving a number of separate watersheds can be adequately and conveniently made.

- The level of detail of the analysis in the methodology must be consistent with the available data and the time and space scales of the problem.

- The methodology must be able to take into account variability in annual hydrology and in storm-event water quality.

- The methodology must be tested in a calibration/verification process in order to gain confidence in the methodology.

- The methodology should be consistent with accepted practice and, if possible, should be corroborated by other data (e.g., NURP) and methods utilized elsewhere.

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- The methodology should be consistent with accepted practice and, if possible, should be corroborated by other data (e.g., NURP) and methods utilized elsewhere.

Methods to estimate loads generally fall under one of two categories, namely:

- Empirical methods, which are based on the analysis and interpretation of measured data

- Modeling methods, which use mathematical algorithms to simulate the physical and chemical factors affecting the watershed runoff and water quality

When discussing the methodology to estimate loads, it is useful to consider it as having two aspects: estimating the volume of runoff and estimating the quality of the runoff. In this study, we used a modeling approach to estimate runoff volumes and an empirical approach for water quality. The following discusses the hydrologic and water quality methodologies.

8.4.2 Hydrologic Component of Loading Methodology

The hydrologic component of the loading methodology utilized a continuous watershed model, because hydrologic watershed models are well understood and accepted. Moreover, a continuous model can conveniently be applied to predict runoff volumes from the Study Area for a range of years and corresponding hydrologic and watershed conditions. The hydrologic model chosen was EPA's Stormwater Management Model (SWMM Version 4.0) because it has the required hydrologic features (such as continuous simulation, and soil moisture accounting), and also has the capability of simulating selected control measures (e.g., detention basins). The model inputs were derived from precipitation data, land use data, soils information, and topographic information compiled from available sources, principally the SCVWD.

To improve the confidence in the modeling results, the model predictions were compared to field data in a process referred to as calibration and verification. The calibration phase involved selection of a portion of the data set and adjustment of model coefficients to improve agreement with this subset of the data. Following calibration, the verification phase involved comparing model predictions with the remaining data without adjusting the model coefficients. The degree of agreement between the model predictions and the measured data is a measure of the model's reliability, and was used to estimate the uncertainty associated with the model's predictions of load in Appendix H.

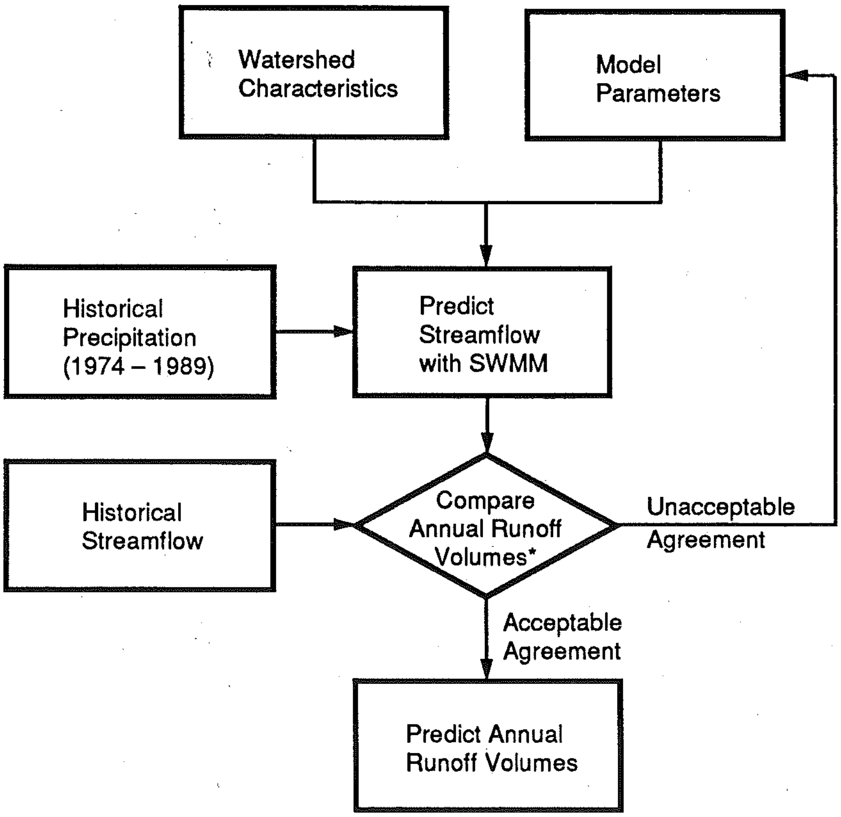
The following describes specific steps in the model calibration/verification shown schematically in Figure 8-2.

(1) Based on analysis of available historical precipitation and flow data, select the wet-weather period of October through April and the period of record as water years 1974-1989.

(2) Using a portion of the period of record, calibrate the continuous SWMM Model by adjusting model parameters to achieve agreement between predicted and measured annual streamflows on selected gaged watersheds.

(3) Using the remaining period of record, verify SWMM model by comparing predicted versus measured annual streamflows without adjusting model calibration parameters.

Details describing the model inputs, the calibration and verification process, and the wet-weather runoff predictions for the Study Area are provided in Appendix B.


Watershed Characteristics
Model Parameters
Historical Precipitation (1974 – 1989)
Predict Streamflow with SWMM
Historical Streamflow
Compare Annual Runoff Volumes*
Unacceptable Agreement
Acceptable Agreement
Predict Annual Runoff Volumes

* Model results compared to measured

Figure 8-2. HYDROLOGY MODEL CALIBRATION / VERIFICATION FLOWCHART

8.4.3 Water Quality Component of Loading Methodology

The water quality component of the loading methodology was empirical and was based on the analysis and interpretation of the water quality data in Section 6.0. The approach follows closely that utilized in the NURP and FHWA programs, which is based on a statistical characterization of the event mean concentrations using a lognormal distribution. The advantage of this approach is that it provides the best estimate of the central tendency of the data (namely the median in log space) and the mean used in estimating loads. The method also formally characterizes the variability in the data in terms of the coefficient of variation. Another important advantage of the method is that there is an extensive data base (i.e., NURP and FHWA) which has been analyzed in a similar fashion and against which comparisons can be made (Section 6.0).

The alternative to this "statistical method" would be to model the water quality using a mathematical formulation such as the "buildup-washoff" routine in SWMM. This method, although intuitively appealing, has had only limited success when applied to actual projects. Moreover, the method predicts water quality throughout the storm event, whereas for the purpose of estimating loads, it is sufficient to predict the event mean concentration for storms.

A second alternative to the statistical method would be to utilize regressions of water quality to hydrologic factors (e.g., volume of runoff, flowrate) or other factors. We investigated this approach and, as described in Section 6.0, various regressions were evaluated. However, regressions were inadequate to reliably estimate loads.

Fortunately, even though the water quality component of the loading was empirical, the study design, by incorporating land use and stream stations, provided a means of calibrating the loading methodology. This was performed by estimating the loads based on the volumes of runoff from the various land uses predicted by SWMM multiplied by the mean land use concentrations estimated based on the analysis in Section 6.0 (Table 8-2). This estimate is the predicted load. The measured load was estimated based on flow and water quality measurements at the stream stations, where again, the mean stream concentrations, given in Table 8-2, were estimated based on the analysis in Section 6.0.

Steps in the loading methodology calibration process, shown schematically in Figure 8-3, were as follows:

(1) Statistically analyze runoff water quality for land use stations. Aggregate land use stations into categories with similar water quality characteristics. Pool data for aggregated land use stations and estimate mean concentrations based on fitting data to lognormal distribution.

(2) Predict annual wet-weather load for 1988-1989 at stream stations based on SWMM predictions and mean water quality estimates from Step 1.

(3) Estimate measured load at stream stations for 1988-1989 based on measured water quality and streamflow at those locations.

(4) Calibrate loading methodology by comparing predicted loads from Step 2 with measured loads for Step 3. Adjust runoff water quality concentrations for land use categories used in the predicated loads to improve agreement.

Details of the loading methodology calibration results are provided in Section 8.6.

8.4.4 Generating Loads for Study Area

Once the hydrologic model was calibrated and verified and the loading methodology calibrated, flows and loads were estimated for the Study Area as follows:

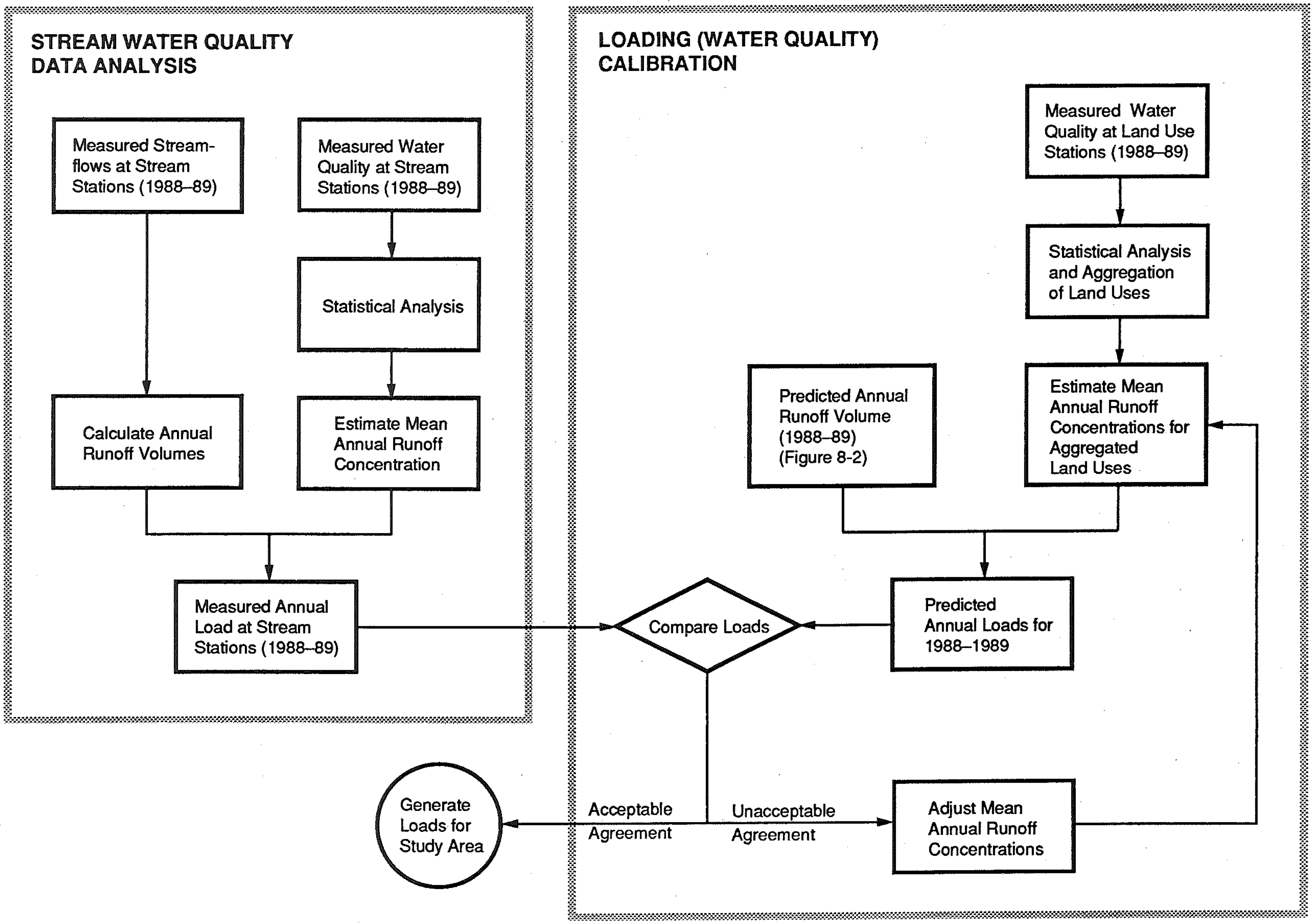

STREAM WATER QUALITY DATA ANALYSIS
Measured Stream-flows at Stream Stations (1988–89)
Measured Water Quality at Stream Stations (1988–89)
Statistical Analysis
Calculate Annual Runoff Volumes
Estimate Mean Annual Runoff Concentration
Measured Annual Load at Stream Stations (1988–89)
LOADING (WATER QUALITY) CALIBRATION
Measured Water Quality at Land Use Stations (1988–89)
Statistical Analysis and Aggregation of Land Uses
Predicted Annual Runoff Volume (1988–89) (Figure 8-2)
Estimate Mean Annual Runoff Concentrations for Aggregated Land Uses
Predicted Annual Loads for 1988–1989
Compare Loads
Acceptable Agreement
Unacceptable Agreement
Generate Loads for Study Area
Adjust Mean Annual Runoff Concentrations

Figure 8-3. LOADING METHODOLOGY CALIBRATION FLOWCHART

(1) Based on calibration and verification of selected gaged watersheds, estimate runoff model coefficients for ungaged watersheds.

(2) For each of 11 watersheds, generate annual wet-weather runoff volumes for each land use category (open, commercial/residential, industrial) for period of record.

(3) Estimate annual loads for each watershed by multiplying the runoff concentration (corrected based on the loading calibration) for each land use category times predicted runoff from that land use category. Sum loading contributions for all land uses in each watershed. Sum loading contributions for all 11 watersheds.

8.4.5 Key Assumptions

Key assumptions in the wet-weather loading methodology are as follows:

(1) The specific storms monitored are representative of the 1988-1989 wet-weather season, and the mean concentrations estimated from the analysis of the storm event data are good estimates of the annual mean wet-weather runoff concentrations for 1988-1989.

(2) The annual mean runoff concentrations estimated for the data collected in 1988-1989 are representative for other hydrologic conditions in the period of record (i.e., 1974-1989).

Assumption (1) is considered a reasonable assumption, as an analysis of the characteristics of the storm events sampled in 1988-1989 shows that the events sampled were indeed typical of events that year. Also, because approximately one-half of the major storm events (7 of 15) were sampled, the sample set is adequate to estimate a mean annual concentration.

The validity of assumption (2) is more difficult to address, because these data were taken during drought conditions and sampled storm volumes were not representative of the range of storm volumes based on long-term statistics. Specifically, in Section 5.0, we show that monitored storm volumes ranged between the 10th and 60th percentiles, based on long-term rainfall statistics. Thus, there is the potential for bias in the water quality results because of the drier conditions and the smaller storm events that were monitored. Unfortunately, there are no data from comparable multi-year studies that indicate how annual mean water quality data might vary (if at all) in response to annual rainfall variations. Interpretation of loading estimates based on these data should therefore take these factors into consideration.

8.5 FLOW AND LOADING RESULTS

Loading estimates utilizing the methods just described were made for those constituents which were consistently measured at levels well above detection limits and which are of general environmental interest. These constituents were cadmium, chromium, copper, lead, nickel, zinc, nitrate-nitrogen, total Kjeldahl nitrogen, total phosphate, BOD, and TSS.

8.5.1 Wet-Weather Runoff, Wet-Weather Release, and Dry-Weather Loads

Table 8-3 summarizes annual load statistics for these constituents associated with the wet-weather runoff, dry weather, and wet-weather reservoir releases.

Table 8-3 shows that the load has a large range. This range reflects the large variability in annual runoff illustrated in Figure 8-4. Figure 8-4 shows that wet-weather runoff and reservoir releases during wet years provide most of the water that ultimately gets to the Bay. The figure also shows that wet-weather reservoir releases are only important during three or four of the wetter years.

Table 8-3. Load Statistics Based on 1977-1989 Hydrology (in thousands of pounds)

WET WEATHER RUNOFF LOADS

	FLOW (ac-ft)	CADMIUM	CHROMIUM	COPPER	LEAD	NICKEL	ZINC	NO3-N	TKN	PO4-P	BOD	TSS
MEDIAN	53,000	0.36	6.1	9.7	10.5	13.5	36.7	91	233	107	1,360	41,500
CV	1.20	0.96	1	0.97	0.93	1	0.87	1.1	1.1	1.1	1.1	1.2
MEAN	83,000	0.5	8.7	13.6	14.3	19.4	48.6	133	348	159	2,030	65,200
MAXIMUM	249,125	1.26	22	34	35	50	115	367	992	459	5,795	196,525
MINIMUM	11,792	0.09	1	2	3	3	10	23	57	27	337	9,320

DRY WEATHER LOADS

	FLOW (ac-ft)	CADMIUM	CHROMIUM	COPPER	LEAD	NICKEL	ZINC	NO3-N	TKN	PO4-P	BOD	TSS
MEDIAN	6,440	0.01	0.06	0.13	0.02	0.04	0.23	40	26	1.8	70	228
CV	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
MEAN	8,050	0.01	0.08	0.16	0.03	0.04	0.29	50	33	2.2	88	285
MAXIMUM	24,613	0.02	0.23	0.5	0.09	0.13	0.87	154	101	7	268	872
MINIMUM	2,050	0.002	0.02	0.04	0.01	0.01	0.07	13	8	1	22	73

WET WEATHER RESERVOIR RELEASE LOADS

	FLOW (ac-ft)	**CADMIUM	CHROMIUM	COPPER	LEAD	NICKEL	ZINC	NO3-N	**TKN	**PO4-P	++BOD	TSS
MEDIAN	10,301		0.19	0.18	0.06	0.23	0.28	5.6				672
CV	8.60		8.6	8.6	8.6	8.6	8.6	8.6				9
MEAN	89,000		1.6	1.6	0.48	2.01	2.4	48.0				5,803
MAXIMUM	319,250		5.8	5.6	1.7	7.2	8.7	173.7				20,841
MINIMUM	274		0.005	0.005	0.001	0.006	0.007	0.1				18

** All measured concentrations were less than the analytical detection limit:
TKN < 1mg/l
PO4-P < 1 mg/l
CADMIUM < 0.2 µg/l

++ No BOD Measurement

CV = Coefficient of variation, equal to the standard deviation divided by the mean.

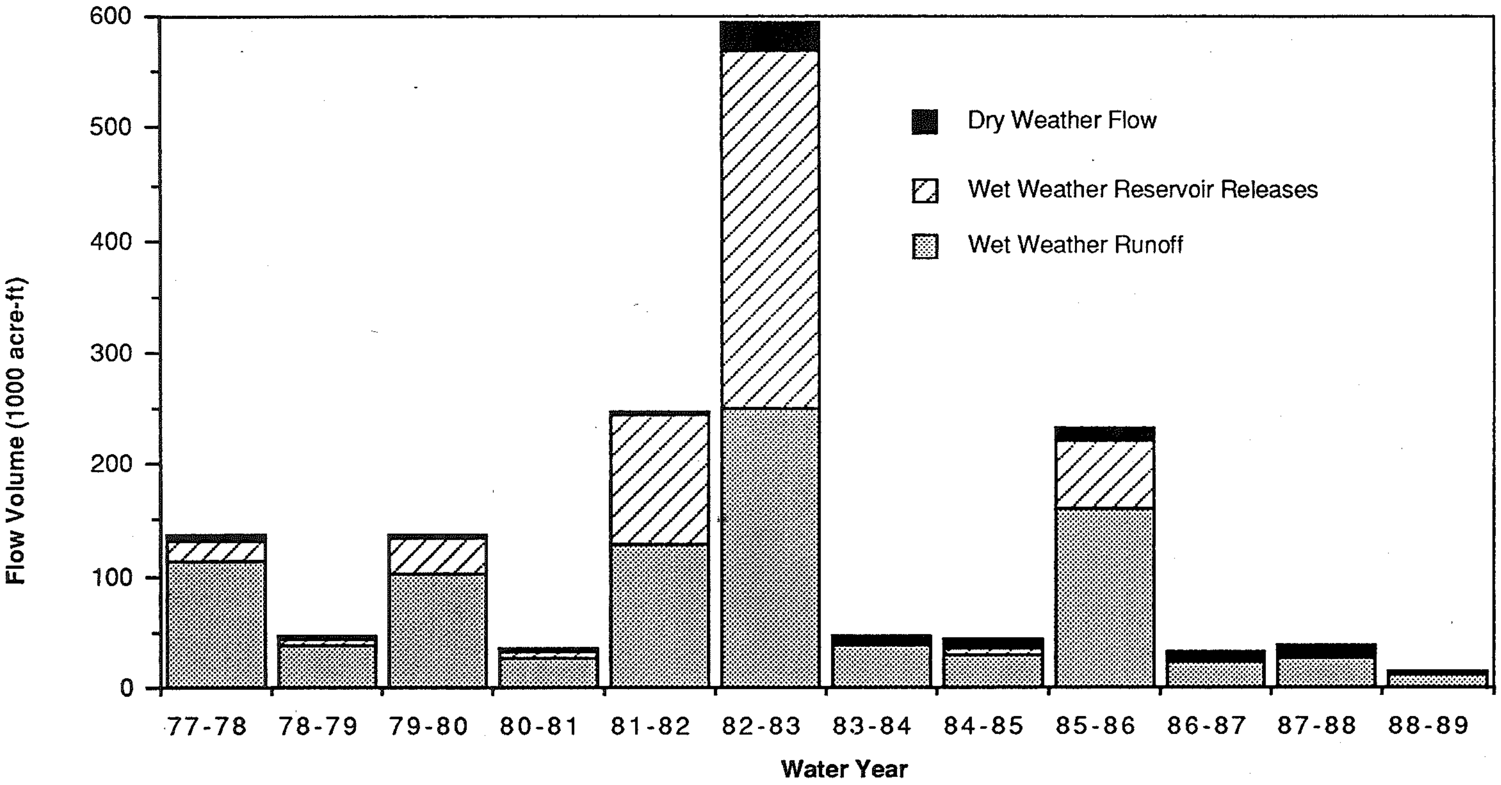


Figure 8-4. Annual Volumes Associated with Wet Weather Runoff, Wet Weather Reservoir Releases, and Dry Weather Flow

The contribution of the various sources to the load differ significantly. This is illustrated in Figure 8-5, which shows the relative contribution of the three sources to the mean annual load for copper, nitrate-nitrogen, and TSS. This figure shows that runoff contributes most of the copper and TSS load, whereas dry weather and reservoir releases account for about one-half of the nitrate load. In general, the runoff source contributes most of the load for all constituents except nitrate-nitrogen.

8.5.2 Annual Loads for Study Area

Table 8-4 shows the estimated annual total load--i.e., the sum of the runoff, reservoir release, and dry-weather loads--for the period 1977 through April 1989. The table shows that the loads vary significantly from year to year. An example of the annual variability of the total load is provided in Figure 8-6. (Note that the prediction for 1989 covers through April, which accounts for most of the total load.) Figure 8-6 shows that predicted loads in the last 2 years have been low because of the less-than-normal precipitation.

The relationship of loads to annual precipitation is shown in Figure 8-7, where the annual copper load is plotted versus the wet-season rainfall recorded at the San Jose National Weather Service gage. The load is seen to increase linearly with rainfall. The annual load of 40,000 pounds corresponds to 1982-1983, the wettest year of record. The load corresponding to the mean annual precipitation of about 13 inches is approximately 10,000 pounds.

Given the annual variability in loads, it is useful to summarize the load data statistically with the lognormal frequency distribution. Figures 8-8 through 8-10 show these distributions for flow and other constituents. In all cases, these data are well described by the lognormal distribution. These figures allow one to estimate the probability of a

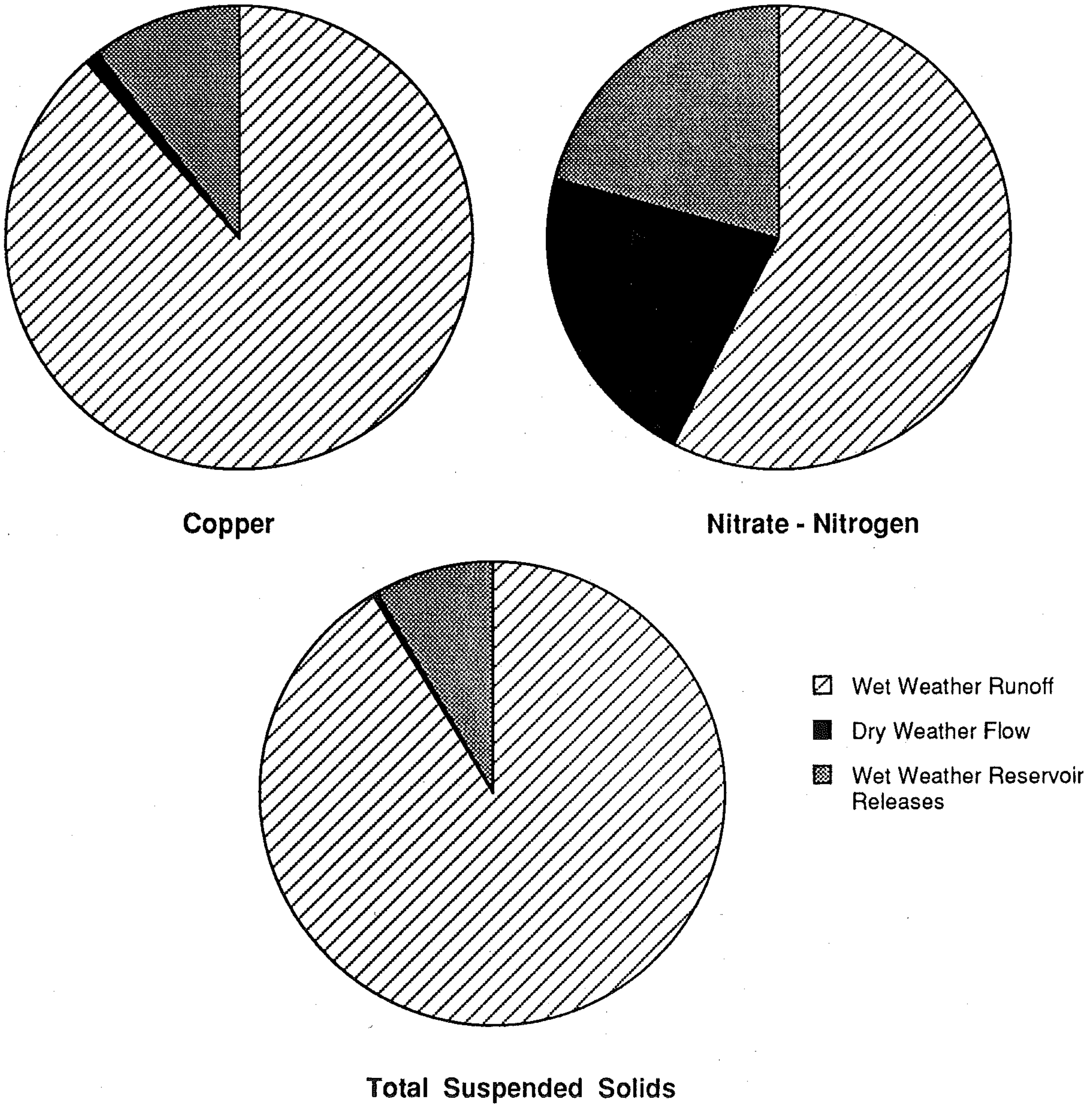


Figure 8-5. Contributing Sources to Mean Annual Loads for Copper, Nitrate-Nitrogen, and Total Suspended Solids

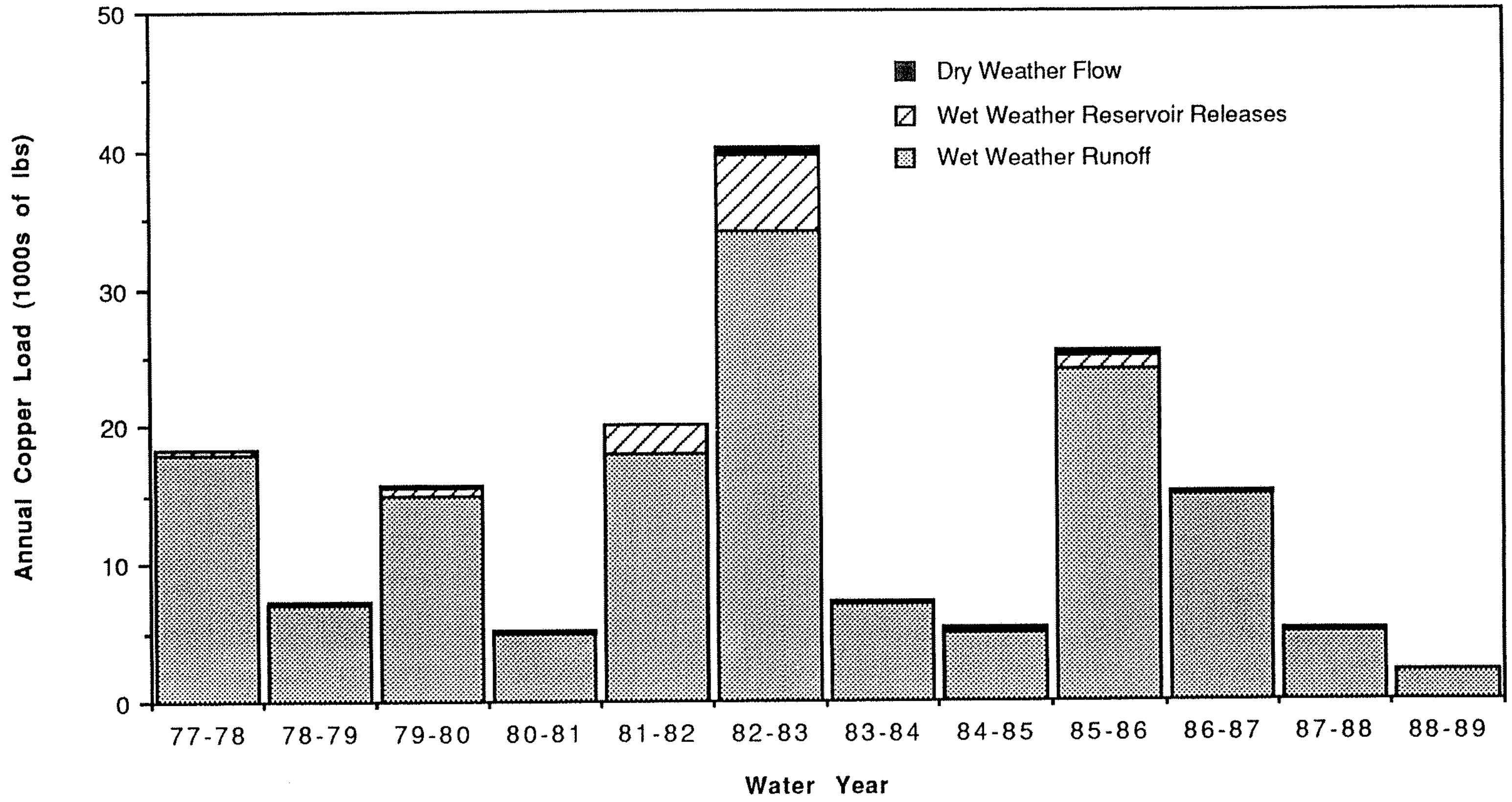


Figure 8-6. Time Series of Annual Total Nonpoint Source Load for Copper

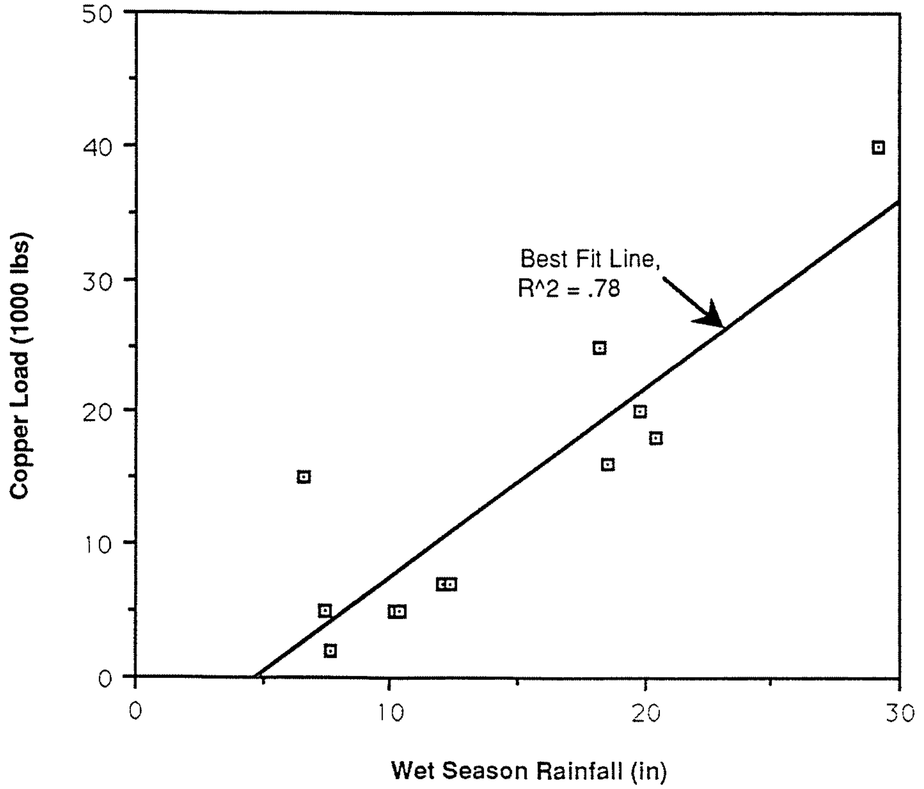


Figure 8-7. Annual Total Load versus Wet-Season Precipitation for Copper

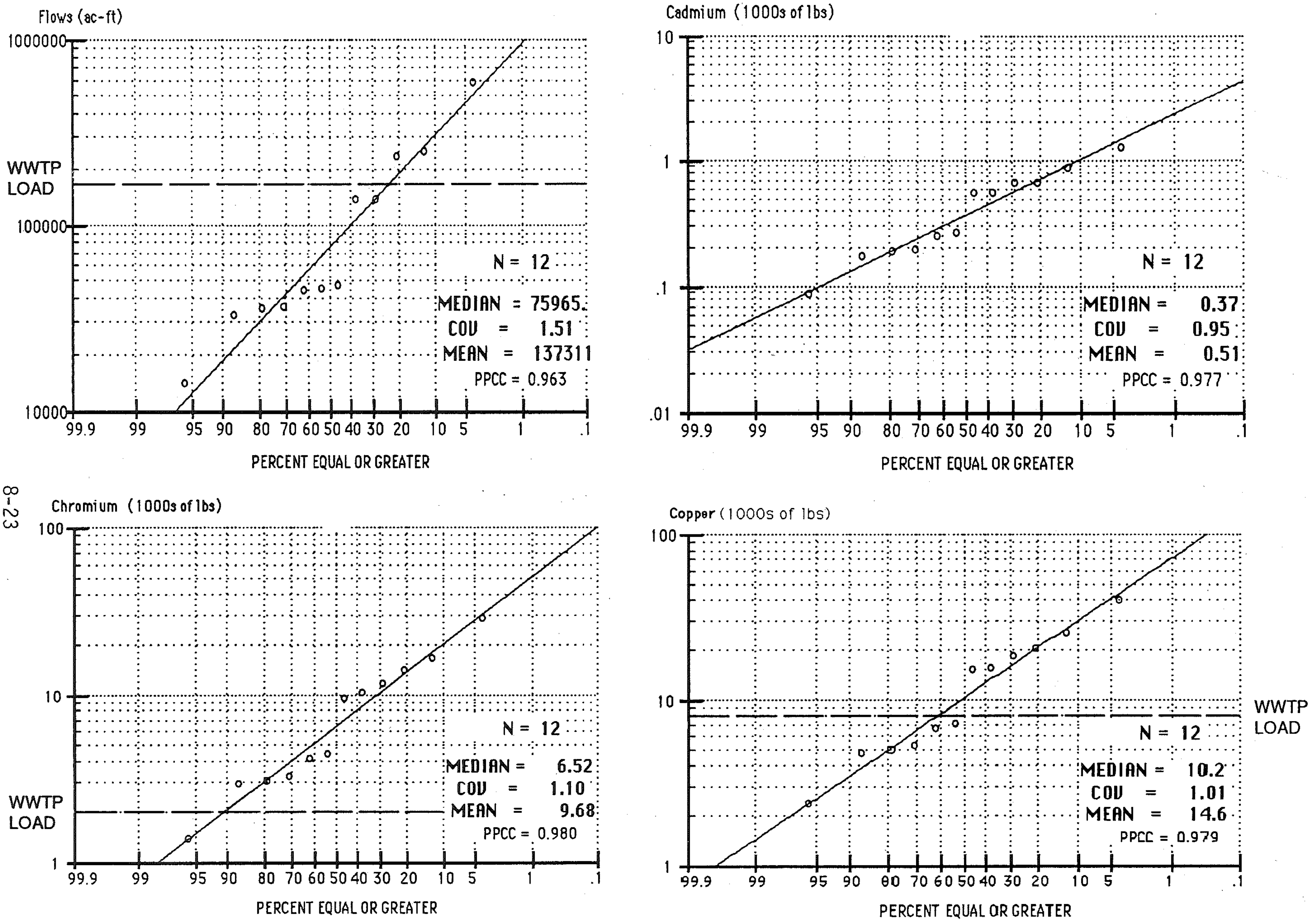


Figure 8-8. Frequency distributions of Annual Flows and Annual Loads for Cadmium, Chromium, and Copper

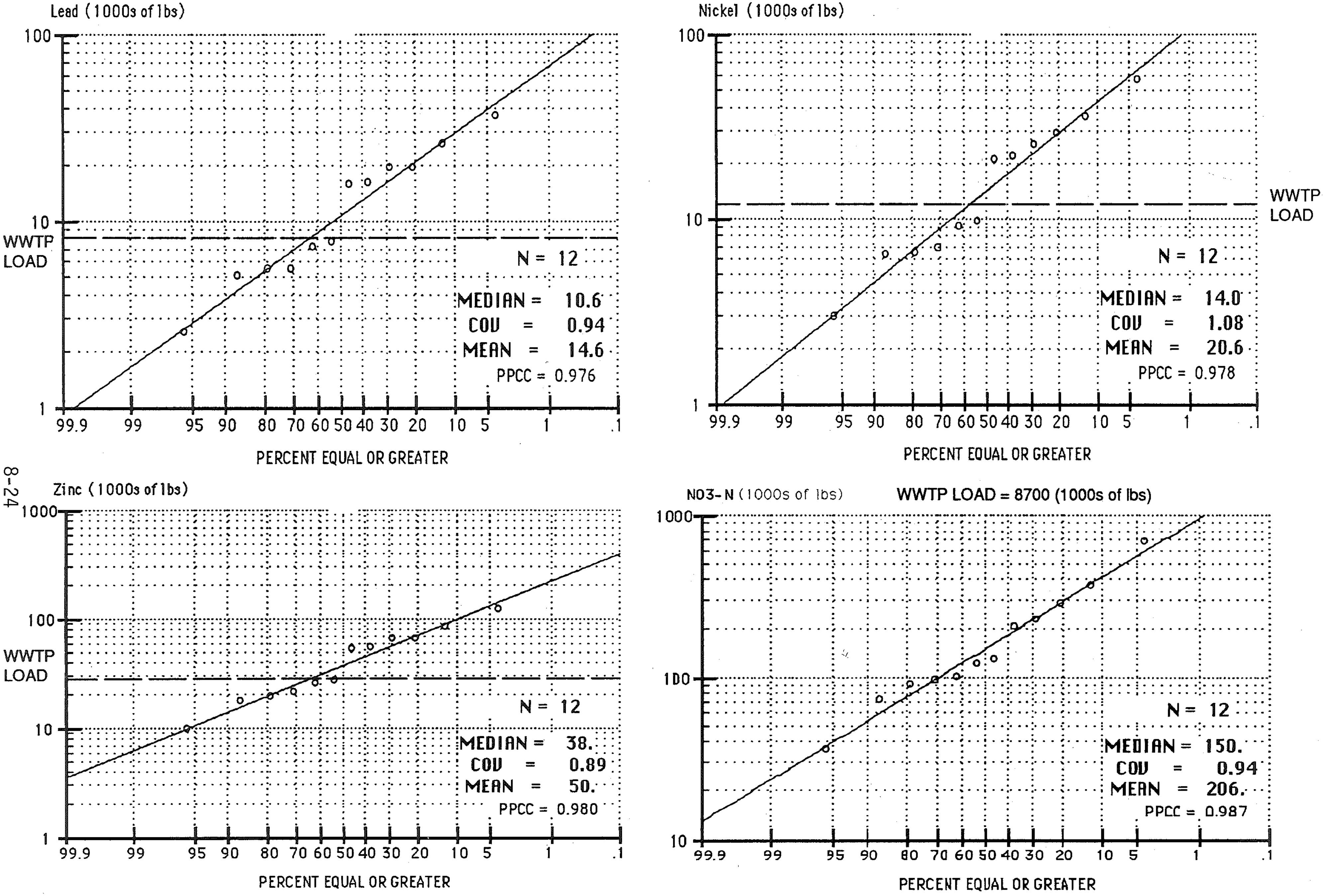


Figure 8-9. Frequency Distributions of Annual Loads for Lead, Nickel, Zinc, and Nitrate.

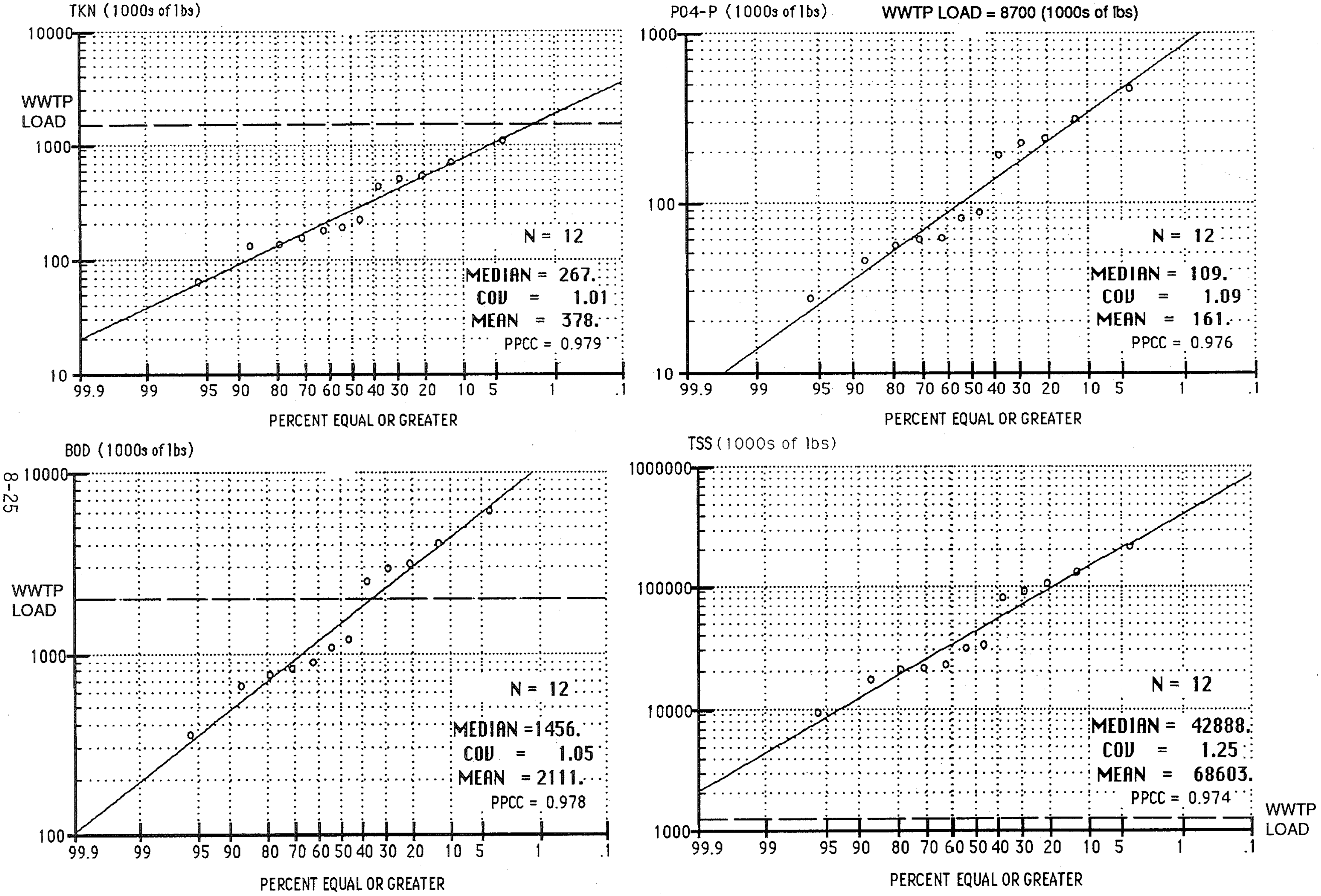


Figure 8-10. Frequency Distributions of Annual Loads for TKN, Phosphate, BOD, and TSS.

given annual load being exceeded; for example, an annual copper load of 20,000 pounds is predicted to be exceeded 20 percent of the years, or one year out of five. Note also that the mean annual Wastewater Treatment Plant (WWTP) load is plotted in these figures for comparison.

To investigate the sensitivity of results to the inclusion of 1982-1983, the statistics were run without that year. The mean load for this case is provided in Table 8-4. Table 8-4 shows, for example, that the mean annual load for copper is 14,600 pounds if 1982-1983 is included in the analysis and 12,100 pounds if 1982-1983 is excluded. The difference of 2500 pounds corresponds to a 17 percent reduction in the estimated mean annual load. The percent reduction for other constituents is similar. The 1982-1983 wet season is estimated to have a return period of about 100 years (Figure 5-6), so the inclusion of this year is conservative (i.e., leads to higher estimates of the mean annual load).

8.6 ASSESSMENT OF THE RELIABILITY OF LOAD PROJECTIONS

Aspects pertaining to the reliability of the pollutant loading projections are discussed in this section. The topics addressed include calibration of the wet weather loading model and the correction factors that were adopted, possible bias in dry weather load estimates due to upstream point source discharges, and the validity of applying the model, which is based on dry year conditions, to years of normal or high annual precipitation. Also summarized is the uncertainty analysis performed on loads estimates (as described in detail in Appendix H).

8.6.1 Calibration of the Wet Weather Loading Methodology

The study design, by incorporating land use and stream stations, provided a means of calibrating the loading methodology. This was performed by estimating the loads based on the volumes of runoff from the various land uses predicted by SWMM (Appendix B, Section B.4.3) multiplied by the mean land use concentrations estimated based on the water quality

Table 8-4. Annual Load Estimates for Study Area

TOTAL LOADS (in thousands of pounds)

YEAR	FLOW (ac-ft)	CADMIUM	CHROMIUM	COPPER	LEAD	NICKEL	ZINC	NO3-N	TKN	PO4-P	BOD	TSS
77-78	136,817	0.7	12	18	19	26	66	228	509	226	2,921	90,697
78-79	47,033	0.2	4	7	7	9	26	97	192	81	1,069	30,763
79-80	137,288	0.6	10	16	16	22	54	205	438	192	2,498	80,350
80-81	35,433	0.2	3	5	5	6	18	73	136	56	751	21,211
81-82	248,086	0.7	14	20	20	29	67	287	540	239	3,087	106,834
82-83	592,988	1.3	29	40	36	57	124	695	1,093	465	6,064	218,238
83-84	45,224	0.3	4	7	8	10	28	128	222	88	1,187	33,028
84-85	44,761	0.2	3	5	6	7	20	122	177	62	894	23,137
85-86	234,350	0.9	17	25	26	36	86	366	722	311	4,062	130,529
86-87	32,824	0.6	10	15	16	21	57	92	131	45	652	17,139
87-88	36,483	0.2	3	5	6	7	21	102	155	61	819	21,710
88-89	14,115	0.1	1	2	3	3	10	36	65	27	359	9,411
MEDIAN	76,000	0.37	6.5	10.2	10.6	14	38	150	267	109	1,460	42,900
CV	1.5	0.95	1.1	1.0	0.94	1.1	0.89	0.94	1.01	1.1	1.05	1.3
MEAN	137,000	0.51	9.7	14.6	14.6	20.6	50	206	378	161	2,110	68,600
MAXIMUM	592,988	1	29	40	36	57	124	695	1,093	465	6,064	218,238
MINIMUM	14,115	0.1	1	2	3	3	10	36	65	27	359	9,411
MEAN**	97,000	0.43	7.8	12.1	12.4	16.9	43	163	309	131	1,723	54,000

** mean values excluding the 1982/83 flood year analysis in Section 6.0 (Table 8-5). This estimate will be referred to as the predicted load. The measured load was estimated based on flow and water quality measurements at the stream stations where, again, the mean stream concentration, given in Table 8-5, was estimated based on the analysis in Section 6.0.

Table 8-6 shows the results of comparing the predicted versus measured loads at stream stations. The table shows the predicted versus measured loads for 1988-1989 for selected constituents and the percent differences between the two.

8.6.1.1 Metals. For the metals the percent differences are negative (indicating an underprediction) except for positive (overpredictive) values of 10 percent (cadmium at station S3) and 47 percent (zinc at station S4). The former reflects a relatively low measured mean cadmium concentration (1.4 µg/L) at station S3; the latter difference is caused by the relatively large industrial land use projected to be upstream of S4 (15 percent) and the relatively high observed mean zinc concentration (1206 µg/L) at the single industrial land use site (Table 8-5). Otherwise, the predicted loads are always less than the measured loads. This is because the stream concentrations tend to be higher than the land use concentrations, especially for constituents that tend to be associated more with the suspended sediment. The maximum negative percent difference is -63 percent for nickel at station S3.

This level of agreement is considered quite good for a nonpoint source loadings comparison, especially given the size of the catchments. Nonetheless, given the consistent bias between predicted and actual loads, we chose to develop a calibration "correction factor" as shown at the bottom of Table 8-6. This factor is the ratio of the total measured load at all four stream stations divided by the total predicted load. These factors were applied to the mean concentrations in Table 8-5 prior to making wet-weather loading estimates for the Study Area.

Table 8-5. MEAN CONCENTRATION OF RUNOFF FROM MONITORING STATIONS

LANDUSE TYPE	STATIONS	SEASON	N	Cadmium µg/L	Chromium µg/L	Copper µg/L	Lead µg/L	Nickel µg/L	ZINC µg/L	BOD mg/L	NO3-N mg/L	PO4-P mg/L	TKN mg/L	TSS mg/L
INDUSTRIAL	L2	WET	5	5.9	39.1	52.9	133.5	54.0	1471	13	0.6	0.7	1.8	152
RESIDENTIAL/ COMMERCIAL	L1,L3,L4, L5,L6	WET	25	1.7	21.1	50.5	60.8	40.9	251	10	0.7	0.3	2.1	76
OPEN	L7	WET	5	0.6	10.0	9.0	4.0	18.4	10	5	0.2	0.19	1.1	85
RESERVOIRS	R1 to R6	DRY	6	<0.2	7.0	6.0	2.0	8.0	10	-	0.2	<1	<1	24
STREAM	S1	WET	5	2.2	28.3	52.5	63.4	66.2	268	11	0.5	0.56	1.9	190
	S2	WET	7	2.3	41.7	69.1	64.5	51.8	337	17	0.5	0.90	2.1	234
	S3	WET	6	1.6	40.8	79.1	85.6	107.4	294	8	0.6	1.10	2.4	454
	S4	WET	6	3.2	45.2	65.6	82.0	98.5	263	11	0.9	0.73	1.5	248
STREAM	S1,S2, S3,S4	DRY	12	0.3	3.5	7.4	1.4	2.0	13	4	2.3	0.10	1.4	13

Note: Based on estimate of median and coefficient of variation as described in section 6.0

Table 8-6. RESULTS OF CALIBRATION OF LOADING METHODOLOGY

Station (year)	Cadmium (lbs)	Chromium (lbs)	Copper (lbs)	Lead (lbs)	Nickel (lbs)	Zinc (lbs)	NO3-N (lbs)	TKN (lbs)	PO4-P (lbs)	BOD (lbs)	TSS (lbs)
S-1 Calabazas Creek (1988-89)											
Predicted	1.9	26	62	75	51	311	830	2655	348	12360	94452
Measured	2.7	35	66	79	83	337	624	2280	700	14112	237600
* Percent Difference	-29%	-26%	-5%	-5%	-39%	-8%	33%	16%	-50%	-12%	-60%
S-2 Sunnyvale East Channel (1988-89)											
Predicted	2	24	58	120	61	290	773	2,470	323	11,494	87,776
Measured	3	49	145	163	105	390	590	2,280	1,041	19,983	372,555
* Percent Difference	-33%	-50%	-60%	-26%	-42%	-26%	31%	8%	-69%	-42%	-76%
S-3 Guadalupe River (1988-89)											
Predicted	6	72	163	206	136	991	2,161	6,997	1,004	33,340	273,397
Measured	5	139	270	292	366	1,001	2,114	8,182	3,750	27,954	1,547,672
* Percent Difference	17%	-48%	-40%	-29%	-63%	-1%	2%	-14%	-73%	19%	-82%
S-4 Coyote Creek (1988-89)											
Predicted	16	158	339	471	286	2,795	4,465	14,194	2,390	71,062	604,344
Measured	22	311	451	564	677	1,808	6,119	10,313	5,019	74,253	1,705,067
* Percent Difference	-28%	-49%	-25%	-16%	-58%	55%	-27%	38%	-52%	-4%	-65%
** Loads Correction Factor	1.27	1.91	1.50	1.26	2.30	0.81	1.15	0.88	2.59	1.06	3.64

* Percent Difference = (predicted loads - meas. loads)/meas. loads

** Loads Correction Factor = (sum of meas. loads)/(sum of corrected pred. loads)

8.6.1.2 Other Constituents. Total phosphate tended to be underpredicted by as much as 73 percent; as phosphate tends to be associated with the particulate fraction, this is consistent with the bias observed with the metals.

The constituents that tend to be more dissolved than particulate showed relatively good agreement. These constituents with their overall calibration factors were nitrate (1.17) and TKN (0.89). The predicted versus measured BOD was also close, resulting in a correction factor of only 1.07. As with the metals, the correction factors given in Table 8-6 were applied prior to making loading estimates.

8.6.2 Discussion of Correction Factors

As indicated above, the use of correction factors was required to compensate for differences between the stream concentrations projected to result from land use runoff and observed wet weather concentrations in the streams. These discrepancies occured only with the concentrations; model flow projections produced good matches with observed stream flow data.

We believe it to be most likely that the pollutant concentrations in the streams observed during storm runoff periods are the result of a combination of the land-side storm runoff and some presently undefined factor. The present level of information prevents the formal incorporation of a mechanism for such a factor into the methodology, and the use of a correction factor provides the only feasible basis for recognizing the observed conditions.

At this time, we speculate that the discrepancy in pollutant concentrations at the stream stations is most probably attributable to scour and resuspension of stream bed materials under the higher stream flow regimes during runoff periods. This material is postulated to deposit during dry periods from contribution by base flows, upstream point sources, and runoff following recession of the hydrograph. Since this material can be presumed to eventually enter the bay following a sufficiently long sequence of storm pulses, it is therefore more appropriate to assign more weight to the observed stream concentrations than to the land-side load projections for developing estimates of loads to the bay. The use of the correction factors is an empirical response to this situation.

Several observations relating to the data obtained by this study provide circumstantial support for the suggestion that stream bed materials are an important contributor to wet weather stream concentrations and loads, being higher than the quantities delivered from land runoff during a storm event.

- Analysis of the upstream point source discharge contributions (see 8.6.3 below) indicates that much of the flow and pollutant load is lost between the discharge points and the stream monitoring stations. It is probable that the particulate fractions of pollutants become incorporated in the bad material.
- Appreciably higher pollutant concentrations were observed during the first storm of the season at stream stations, but not at land use sites. This is not inconsistent with the source being the accumulation of stream bed materials over the extended dry season.

8.6.3 Assessment of Possible Bias in Dry-Weather Load Estimates

The issue examined here is the possibility that upstream point source discharges may influence the water quality at a monitored stream station in a way that would bias the dry weather loading projections for unmonitored streams, which are based on monitoring results for the four stream stations selected for the study. If the point source discharges have a significant influence on pollutant concentrations observed at these stations, then direct use of observed water quality might provide overestimated concentrations and loads for streams that had either no point source inputs or which had appreciably smaller (or different) point source inputs.

The discharge flows and pollutant loads have been listed and summarized in Appendix G, for each watershed. Table 8-7 summarizes the total discharge flows, the mass load for the dry season, and the flow-weighted concentration of selected pollutants in the point sources discharged above each stream station. It compares these results with the measured flows and concentrations (and dry season loads) of the same pollutants at the stream monitoring station they would influence. The comparison is shown for zinc and copper for three of the streams, and zinc and nickel for Coyote Creek. These were the only pollutants detected in the treated discharges with any consistency.

The results of this analysis indicate that the point source average discharge flows are two to nearly five times greater than the average dry weather flows observed at the stream stations. Both flow records appear to be sufficiently reliable for this analysis, since the averages are based on an appreciable number of observations. The point source data are based on weekly records covering an appreciable portion of 1987, the year for which records were furnished. The quality data on metals are based on a single set of samples in response to the special request to the dischargers by the Regional Board, to provide quality information on metals. The analysis assumes that the point source discharge rates are essentially the same in 1988-89 as they were in 1987-88, and can be assigned to the period for which the quality data (streams and point sources) are available.

We have accordingly concluded that, the indicated differences being approximately correct, the difference reflects stream bed losses by subsurface percolation (and/or evaporation, plant uptake, etc.) in the stream reaches between the discharges and the stream monitoring station.

A similar pattern is exhibited in most cases for pollutant concentrations and dry season mass loads, suggesting losses to the stream sediments.

TABLE 8-7 Comparison of Point Source Discharges with Stream Station Data

DRY SEASON - 1988-1989

CALABAZAS STA S-1

	Disch Q (ac-ft)	Disch Q (cfs)		Conc µg/l Cu	 Zn	Load lbs/season Cu	 Zn	% of Total Load Cu	 Zn
Point Sources	203	0.670	462%	9.5	63	5.2	35	627%	527%
S-1 TOTAL	44	0.145	100%	7	12	0.8	1.4	100%	100%

SUNNYVALE EAST STA S-2

	Disch Q (ac-ft)	Disch Q (cfs)		Conc µg/l Cu	 Zn	Load lbs/season Cu	 Zn	% of Total Load Cu	 Zn
Point Sources	192	0.633	300%	0.5	29	0.26	15.1	50%	970%
S-2 TOTAL	64	0.211	100%	3	9	0.52	1.6	100%	100%

GUADALUPE STA S-3

	Disch Q (ac-ft)	Disch Q (cfs)		Conc µg/l Cu	 Zn	Load lbs/season Cu	 Zn	% of Total Load Cu	 Zn
Point Sources	1832	6.038	242%	1.9	20.7	10	103	156%	626%
S-3 TOTAL	758	2.498	100%	3	8	6	16	100%	100%

COYOTE STA S-4

	Disch Q (ac-ft)	Disch Q (cfs)		Conc µg/l Ni	 Zn	Load lbs/season Ni	 Zn	% of Total Load Ni	 Zn
Point Sources	1623	5.347	200%	130	0.004	570	0.02	12989%	0%
S-4 TOTAL	812	2.676	100%	2	14	4.4	30.7	100%	100%

On the basis of the following factors, we determined that the procedure adopted for estimating dry weather loads does not result in biased estimates by failing to specifically factor in point source discharges in some way. Nor does the load estimation procedure result in biased estimates of loads to the bay.

- For those pollutants that are present in point source discharges, the available data do not provide a basis for identifying any relationship between upstream point source discharges and monitored downstream conditions.
- The data suggest that a substantial portion of the flow and the pollutants it does carry do not reach the downstream stations (and the bay) during dry weather periods.
- Only a few (zinc, copper, and nickel) pollutants are indicated to be present in detectable quantities at some of the discharges. None of these are reported in all discharges.
- Dry weather loads are a minor component of the total loads to the bay.

8.6.4 Assessment of Application of Load Model to Normal and Wet Years

Monitoring data assembled by the study were obtained during a dry year relative to the overall hydrologic pattern for the area. The load projections incorporate the year-to-year differences in runoff discharge volumes adequately, because a sufficient data record is available for reliably defining the variations in rainfall that occur. However, an element of uncertainty in load projections results from the lack of data which would permit the determination of any relationship between the amount of rainfall during a year and the characteristic concentration of a pollutant (e.g., the site median concentration, SMC) in the stormwater discharges.

While it is not possible to definitively resolve this issue with the presently available data base, we believe that there is a relatively high probability that annual rainfall differences will not have a substantial effect on load projections over and above the incorporated effect on discharge volume. The considerations that led to this assessment include the following.

1. Concentrations may be either higher (increased erosion, scour) or lower (increased dilution of relatively fixed amount of pollutants on the surface). If the basic difference between a wet and dry year were produced by a difference in storm size (intensity, duration, volume), then factors such as scour and dilution would be important and runoff SMCs would be more likely to be influenced by annual precipitation levels.

   However, analysis of the rainfall record suggests that a major difference between a wet and dry year is the average number of storms. Years that have more than 17 inches of rain average about 32 storms per year, almost double the 17 storm events in years that receive less than 9 inches of rain. The size of the average storm event changes to a smaller extent, 0.6 inches for wet years versus 0.4 inches in dry years.

   If the storm sizes for which data have been obtained are not much different in wet and dry years, then the runoff quality data obtained are more likely to be largely independent of annual rainfall totals.

2. The longer dry periods between storms during dry years (a result of fewer events) would theoretically permit greater surface accumulation of pollutants and increased material washed off during a particular storm event, with corresponding increases in concentration during these periods. However, commonly accepted accumulation rate functions

indicate a relatively rapid buildup to a plateau, so that extended dry periods do not increase the surface accumulations available for washoff. Monitoring data for the land use sites in this study do not reflect elevated concentrations for the first storm of the wet season compared with levels in subsequent events.

3. Analysis of the rainfall record indicates there to be a three- or fourfold difference in annual precipitation between wet and dry years (Figure 5-6). Potential concentration differences would be anticipated to be substantially smaller in magnitude, should they occur at all. The implication is that the hydrology differences which are accounted for in the projections, would account for the major portion of the load differences.

On the basis of the foregoing, there is no satifactory reason for modifying runoff concentrations on the basis of annual rainfall. There is a qualitative basis for believing that runoff concentrations will not be significantly different in wet and dry years. Because of this, and the fact that runoff volume differences, which the loading methodology does account for, would exert the dominant effect on load differences, we conclude that the load projections developed are reasonable estimates for the range of years used.

8.6.5 Uncertainty in Annual Load Estimates

As described in detail in Appendix H, an uncertainty analysis was performed to quantify confidence bounds on annual load estimates. The uncertainty analysis accounted for the following components of the total uncertainty in loads estimates:

- Uncertainty in the estimate of the mean concentrations for each land use
- Errors in model flow predictions in calibrated areas
- Errors in model flow predictions in uncalibrated areas

A first-order uncertainty analysis technique was used to compute the mean and variance in load estimates due to the variance in concentration and flow estimates. Results of the uncertainty analysis were expressed in terms of 90 percent confidence bounds. These confidence bounds determine the range within which one is 90 percent confident the true value of load lies.

For the mean annual load estimate, 90 percent confidence bounds were on the order of plus or minus 50 percent away from the mean estimate. For example, the analysis indicates we are 90 percent certain that the true mean annual copper load (estimated as 14,600 lbs) lies between 8400 and 24,000 lbs. Ninety percent confidence bounds on the mean annual load for all constituents are shown in Table 8-8.

8.7 COMPARISON OF POINT AND NONPOINT SOURCE LOADS

Annual loads were estimated for the three Lower South Bay wastewater treatment plants (San Jose/Santa Clara, Sunnyvale, Palo Alto) based on 1987 and 1988 effluent self-monitoring data. These data are summarized in Table 8-9 and compared with the estimated mean annual load from nonpoint sources. These results are illustrated graphically in Figure 8-11, in terms of the percentage of the total mean annual flows and loads for point versus nonpoint sources. For example, for flow, the figure shows that about 56 percent of the total mean annual flow is from the wastewater treatment plants and 44 percent is from nonpoint sources.

This figure shows that, in general, nonpoint source loads for chromium, copper, lead, nickel, and zinc are at least twice the point source loads, whereas point source loads for the nutrients are much higher. BOD from both sources are comparable. TSS loads almost exclusively derive from nonpoint sources.

Table 8-8. Comparison of Average Annual Point Source versus Nonpoint Source Loads

	Flow (ac-ft)	Chromium (1000 lbs)	Copper (1000 lbs)	Lead (1000 lbs)	Nickel (1000 lbs)	Zinc (1000 lbs)	Nitrate (1000 lbs)	TKN (1000 lbs)	Phosphate (1000 lbs)	BOD (1000 lbs)	TSS (1000 lbs)
WWTP Load	180,000	2	8	8	12	28	8,700	1,500	8,700	2,000	1,300
NPS Load	140,000	10	15	15	21	50	206	378	161	2,100	69,000
Total Load	320,000	12	23	22	33	78	8,906	1,878	8,861	4,100	70,300
Percentage WWTP	56%	18%	36%	35%	37%	36%	98%	80%	98%	49%	2%
Percentage NPS	44%	82%	64%	65%	63%	64%	2%	20%	2%	51%	98%

Table 8-9. Mean Average Annual Wet Weather Loads By Watershed (Based on arithmetic average of 12 years of estimated annual load)

WATERSHED	TOTAL AREA [sq.miles]	FLOW [acre-ft]				CADMIUM [lbs/yr]				CHROMIUM [lbs/yr]				COPPER [lbs/yr]				LEAD [lbs/yr]				NICKEL [lbs/yr]			
		IND	RES	OPEN	TOTAL	IND	RES	OPEN	TOTAL	IND	RES	OPEN	TOTAL	IND	RES	OPEN	TOTAL	IND	RES	OPEN	TOTAL	IND	RES	OPEN	TOTAL
ADOBE, BARRON & MATADERO	34	0	6485	1511	7997	0.0	38.8	3.1	42.0	0	713	79	791	0	1339	56	1395	0	1354	21	1375	0	1663	174	1838
CALABAZAS	21	0	5071	663	5734	0.0	30.4	1.4	31.7	0	557	35	592	0	1047	24	1072	0	1059	9	1068	0	1300	77	1377
COYOTE	123	1357	6085	5904	13345	27.7	36.4	12.3	76.4	276	669	307	1252	293	1257	217	1767	622	1271	81	1974	459	1560	681	2701
GUADALUPE	90	2170	15649	8108	25927	44.3	93.7	16.8	154.9	442	1719	422	2583	469	3232	298	3999	995	3268	111	4375	735	4013	935	5683
LOS GATOS	18	0	2764	283	3047	0.0	16.6	0.6	17.1	0	304	15	318	0	571	10	581	0	577	4	581	0	709	33	741
PERMANENTE	18	0	1567	3146	4713	0.0	9.4	6.5	15.9	0	172	164	336	0	324	116	439	0	327	43	371	0	402	363	765
SAN FRANCISQUITO	8	0	552	846	1398	0.0	3.3	1.8	5.1	0	61	44	105	0	114	31	145	0	115	12	127	0	142	98	239
SAN TOMAS	27	1332	5694	979	8005	27.2	34.1	2.0	63.4	271	626	51	948	288	1176	36	1500	611	1189	13	1814	451	1460	113	2024
SARATOGA	17	0	939	4634	5572	0.0	5.6	9.6	15.2	0	103	241	344	0	194	171	364	0	196	64	260	0	241	535	775
STEVENS CREEK	12	0	1415	130	1546	0.0	8.5	0.3	8.7	0	155	7	162	0	292	5	297	0	296	2	297	0	363	15	378
SUNNYVALE EAST	7	0	1677	0	1677	0.0	10.0	0.0	10.0	0	184	0	184	0	346	0	346	0	350	0	350	0	430	0	430
SUNNYVALE WEST	5	0	1320	1	1321	0.0	7.9	0.0	7.9	0	145	0	145	0	273	0	273	0	276	0	276	0	338	0	339
TOTAL	380	4859	49218	26205	80283	99.3	294.8	54.4	448.5	989	5407	1364	7761	1051	10164	964	12179	2228	10279	360	12867	1645	12622	3023	17290

WATERSHED	TOTAL AREA [sq.miles]	ZINC [lbs/yr]				NO3-N [lbs/yr]				TKN [lbs/yr]				POP4-P [lbs/yr]				BOD [lbs/yr]				TSS [lbs/yr]			
		IND	RES	OPEN	TOTAL	IND	RES	OPEN	TOTAL	IND	RES	OPEN	TOTAL	IND	RES	OPEN	TOTAL	IND	RES	OPEN	TOTAL	IND	RES	OPEN	TOTAL
ADOBE, BARRON & MATADERO	34	0	3599	33	3632	0	14232	853	15085	0	32673	3807	36480	0	13737	2028	15765	0	187408	22448	209857	0	4897439	1274789	6172228
CALABAZAS	21	0	2814	15	2828	0	11128	374	11502	0	25546	1670	27216	0	10741	890	11630	0	146528	9850	156378	0	3829129	559356	4388485
COYOTE	123	4407	3377	130	7914	2552	13353	3332	19237	5533	30655	14871	51059	6705	12889	7920	27514	49789	175834	87689	313312	2042272	4594967	4979611	11616851
GUADALUPE	90	7050	8684	179	15913	4083	34342	4575	43000	8851	78837	20423	108112	10727	33148	10877	54752	79652	452206	120427	652284	3267171	11817256	6838700	21923128
LOS GATOS	18	0	1534	6	1540	0	6065	160	6225	0	13924	712	14637	0	5854	379	6234	0	79868	4201	84068	0	2087145	238537	2325682
PERMANENTE	18	0	870	69	939	0	3439	1775	5214	0	7895	7925	15820	0	3319	4221	7540	0	45284	46730	92014	0	1183381	2653663	3837044
SAN FRANCISQUITO	8	0	306	19	325	0	1211	477	1689	0	2781	2131	4912	0	1169	1135	2304	0	15950	12568	28517	0	416800	713700	1130500
SAN TOMAS	27	4327	3160	22	7509	2506	12496	552	15555	5433	28687	2466	36586	6585	12061	1313	19959	48892	164545	14540	227978	2005462	4299972	825713	7131147
SARATOGA	17	0	521	102	623	0	2060	2615	4675	0	4728	11672	16400	0	1988	6216	8204	0	27122	68824	95946	0	708769	3908307	4617076
STEVENS CREEK	12	0	785	3	788	0	3106	74	3179	0	7129	328	7458	0	2998	175	3172	0	40894	1936	42830	0	1068669	109932	1178600
SUNNYVALE EAST	7	0	931	0	931	0	3680	0	3680	0	8448	0	8448	0	3552	0	3552	0	48460	0	48460	0	1266371	0	1266371
SUNNYVALE WEST	5	0	732	0	732	0	2896	1	2897	0	6648	2	6651	0	2795	1	2797	0	38134	14	38148	0	996534	793	997328
TOTAL	380	15784	27311	579	43674	9141	108009	14788	131937	19818	247952	66009	333778	24017	104252	35155	163424	178333	1422233	389226	1989792	7314906	37166432	22103102	66584439

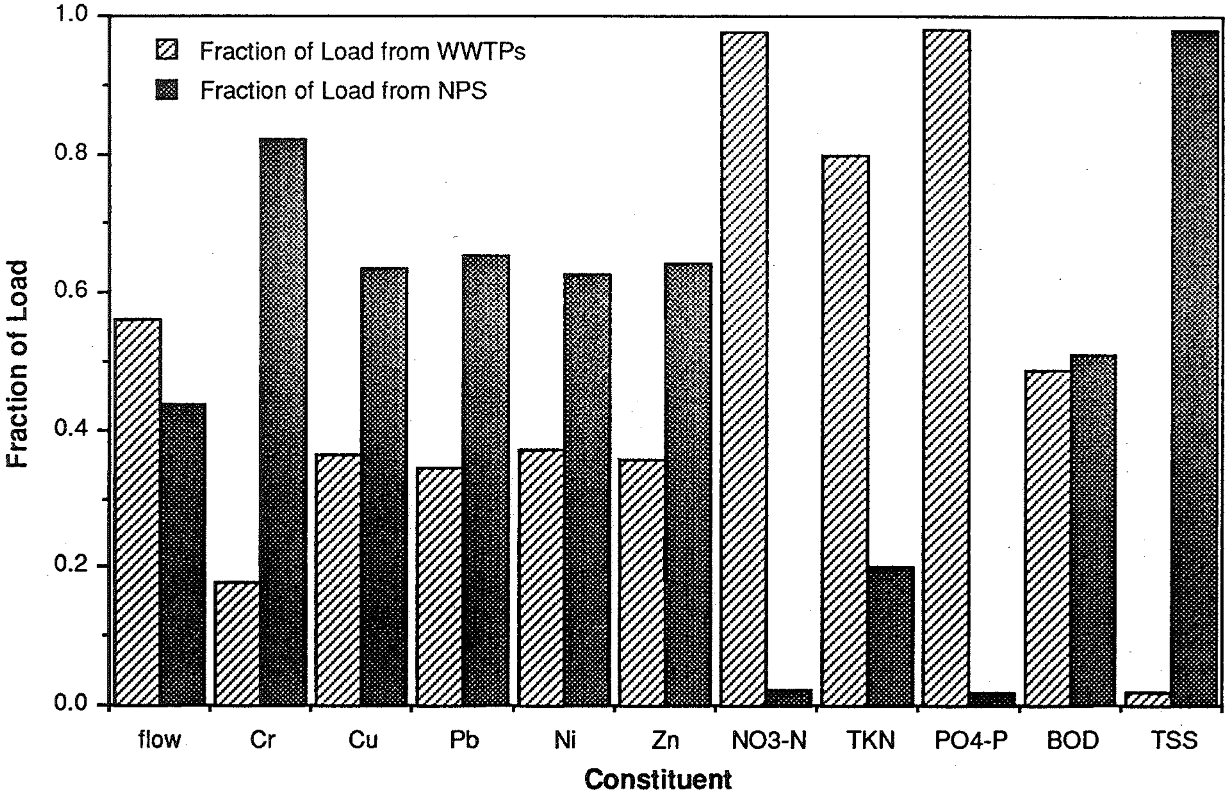


Figure 8-11. Point Versus Non-Point Source Loads

8.8 LOADS FROM INDIVIDUAL WATERSHEDS

Table 8-9 summarizes the average annual load for each watershed. Loads for open, residential/commercial, and industrial land uses are provided along with total watershed loads.

SECTION 9

9.0
SUMMARY AND CONCLUSIONS

The following are the conclusions of the study with regard to hydrology, water quality, sediment quality, toxicity, and loads.

Note that the 1988-89 sampling period spanned two relatively dry years. Storms sampled were typical of this period, but tended to be smaller in volume than the range of events found in normal and wet years. Results of this study could therefore be limited by the lack of wet-year water quality data, and additional sampling will be conducted to verify the results of this study for wet and normal years.

9.1 HYDROLOGY

- Water quality loads are directly proportional to runoff, and thus the watershed runoff characteristics are very important.

- An analysis of long-term precipitation records show that, on average, there are only about 17 major storm events per year with an average duration of 31 hours. Thus the annual nonpoint source loading is associated with relatively few, short storm events.

- Annual flow volumes are highly variable due to changing annual meteorological conditions, and this variability is reflected in annual loads.

- For watersheds with upstream reservoirs, the major source of nonpoint flows is surface runoff from areas below the water supply reservoirs; however, during wet years, reservoir releases are comparable.

- Because of the orographic pattern of precipitation, higher elevations receive substantially greater amounts of rainfall. Runoff from such areas (especially for watersheds without upstream reservoirs) is an important component to surface runoff, especially in the latter part of the winter when antecedent soil moisture levels are higher.

- Dry-weather flows are small relative to wet-weather flows.

- The Stormwater Management Model was utilized to predict runoff from ungaged areas in the Study Area. The model was calibrated and verified using precipitation and streamflow records for the period 1974-1989. Model predictions were generally within 15-25 percent of measured for moderate to wet years at all watersheds where good mass balance could be achieved.

9.2 WATER QUALITY

9.2.1 General

- Concentrations at land use stations were relatively uniform and were not higher for the first storm event of the year.

- Concentrations in streams were higher during the first storm event compared to later events. One hypothesis is that the higher concentrations are created by resuspension of bottom sediment that contains pollutants deposited during the extended summer dry-weather period. (Additional data from first storms of the season are necessary to confirm these observations, which are based on only one storm event.)

- Concentrations of metals in streams generally were higher (by a factor of about 2) than at land use stations for constituents that tend to be associated with suspended sediment. Thus, it appears that resuspension of metals adsorbed to bottom sediment is an important process affecting water quality in the streams. This is supported by relatively good correlations between water quality and turbidity and observed metal levels in sediment samples. The sediment concentrations may be affected by many sources including natural sources, illegal dumping and illicit connections, and stormwater runoff.

- Water quality was distinctly different for these land use categories: open, commercial/residential, and heavy industry. Concentrations at the heavy-industrial sites tended to be two or three times values at commercial/residential sites for cadmium, chromium, lead, zinc, and TSS.

9.2.2 Trace Metals

- Monitoring results indicate that six trace metals (i.e., cadmium, chromium, copper, lead, nickel, and zinc) are generally present in detectable concentrations. Arsenic, mercury, selenium, and silver were generally not detected. In limited sampling, hexavalent chromium was not detected.

- An analysis of exceedances of EPA freshwater criteria was conducted using acute criteria for wet-weather conditions and chronic criteria for dry-weather conditions. Results indicate that during dry weather, concentrations of metals are generally less than chronic toxic criteria.

During wet-weather, copper at all the stream sites generally exceeded the acute criteria, whereas zinc, lead, and cadmium occasionally exceeded criteria.

- The soluble fraction of the trace metals, which is important in evaluating bioavailability, ranged as follows: Lead - less than 5 percent; nickel - 5 to 15 percent; copper, cadmium, chromium - 1 to 25 percent; and zinc - 30 to 50 percent. If acute criteria exceedances at stream stations are reexamined with soluble concentrations, only 1 out of 7 zinc exceedances remained, and only 3 or 4 copper exceedances out of 21 exceedances are retained.

EPA criteria were developed with the intent that they be compared with "acid soluble" concentrations which are between dissolved and total. Therefore, exceedances using total and dissolved can be viewed as upper and lower bounds or exceedances.

9.2.3 Organics

- During wet weather, several organochlorine pesticides (DDE, DDT, etc.) and polynuclear aromatic hydrocarbons (PAHs) were detected at trace levels (<1 μg/L) in about 25 percent of the samples.

- Volatile organics, organophosphorous pesticides, and chlorinated herbicides were seldom, if ever, detected.

- In dry weather, the only class of organics detected more than once was chlorinated herbicides (2,4-D, dicamba).

- The EPA freshwater criterion for organic compounds is only available for organochlorine pesticides. None of the detectable levels of organochlorine pesticides during the wet weather exceeded the acute toxic criteria.

9.3 SEDIMENT QUALITY

- Zinc, chromium, copper, nickel, and lead were consistently detected at levels well above 50 mg/kg, and arsenic and cadmium were consistently found at low levels (<10 mg/kg). With the exception of arsenic, these were the same metals commonly detected in the water. Mercury was measured consistently at trace levels at the Guadalupe River station, likely reflecting the natural mercury deposits in the New Alameda Mine area. Much of the intra-station variability was explained by the percent of silted clay at the station.

- Organochlorine pesticides were commonly observed in sediment samples and consisted of DDT, DDD, DDE, alpha-chlordane, gamma-chlordane, gamma-BHC, beta-endosulfan, and PCBs. These same organochlorine compounds were also observed in stream water samples during wet weather.

- PAHs were detected in 7 of 16 sediment samples, with most of the detections associated with a more sensitive analytic method which was used in the last round of four rounds of sampling. Constituents detected were benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)anthracene, benzo(a)pyrene, fluoranthene, pyrene, and phenanthrene. Except for phenanthrene, these detectable PAH compounds were also detected in the water samples.

- The consistency between the metals and organics detected in the sediment and the water column supports the concept that the stream sediments act as a sink (during low-flow periods) and a source (during high-flow periods) for pollutants.

9.4 TOXICITY

- Tests were conducted to estimate the toxicity of samples of water from stream and land use stations to aquatic life using Ceriodaphnia dubia (a water flea), Pimephales promelas (fathead minnow), and Selenastrum capricornutum (a green alga) as surrogates. Results showed that during dry weather, significant effects were measured in about 15 percent of the tests.

- During wet weather, about 75 percent of the tests showed significant effects on Ceriodaphnia survival, whereas 15 percent of the test showed significantly reduced survivability for fathead minnows.

- Toxic samples did not generally correlate with metals concentrations, although concentrations of several of the metals exceeded ambient water quality criteria for the protection of freshwater organisms.

9.5 LOADS

- The estimated annual pollutant loads are highly variable from year to year, reflecting the variability in runoff volumes (Table 8-4). The highest loads during the period considered were estimated for the 1982-1983 water year, which had the highest runoff flows of record and is estimated to have about a 100-year return period.

- The sources of nonpoint loads were divided into (1) wet-weather runoff from the Valley floor and the foothills below the reservoirs, (2) wet-weather reservoir releases which are primarily associated with spillway flows, and (3) dry-weather flows. The principal source of mean annual metals loads is the runoff component (Figure 8-5). Reservoir releases contribute about 10 percent of the load. The loads associated with dry-weather flows (which includes permitted discharges to the storm drain system) are low except for nitrate-nitrogen, where it accounts for approximately 20 percent of the load.

- When compared with the mean annual loads from the three Lower South Bay wastewater treatment plants, the nonpoint sources account for 60 to 80 percent of the load for chromium, copper, lead, nickel, and zinc, and about 98 percent of the total suspended solids (Figure 8-11). The wastewater treatment plants account for 80 to 97 percent of the nitrate-nitrogen, total Kjeldahl nitrogen, and total phosphate. Both sources contribute equally to the BOD load.

- Uncertainty analysis indicates that the estimated mean annual load has 90 percent confidence bounds of about plus or minus 50-60 percent. Thus, for copper the analysis indicates that we can be 90 percent certain the true value of the mean annual load (estimated vs 14,600 lbs) is between 11,500 and 17,600 lbs. This uncertainty analysis addresses uncertainty in flow and mean concentration estimates, but does not account for the lack of wet-year water quality data.

SECTION 10

10.0
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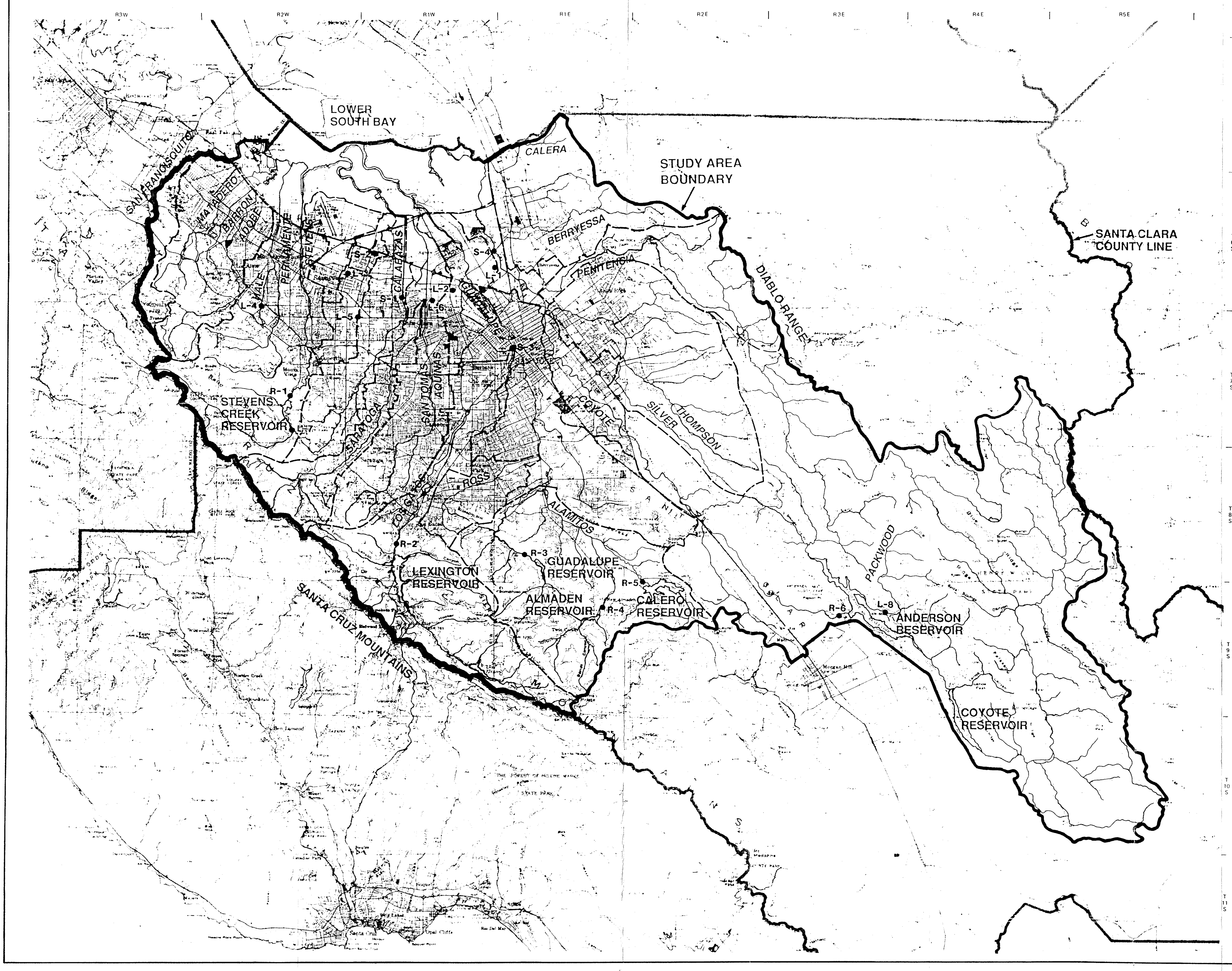

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Figure 2-3
STUDY AREA SHOWING WATERSHEDS
AND SAMPLING STATIONS

Project No. 8720115A	Santa Clara Valley Nonpoint Source Study

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